AN ABSTRACT OF THE THESIS OF

Doug R. Oetter for the degree of Doctor of Philosophy in Geography presented on August 16, 2002.

Title: Land Cover Change along the Willamette River, Oregon.

Abstract approved: ______________________________

A. Jon Kimerling

The Willamette River and its floodplain in northwest Oregon have changed dramatically since European settlement. At one time, the river was a vast complex system of braided channels with a broad floodplain forest; it has now been simplified by channelization and dams, and the forest has been removed to support agricultural and urban expansion. This thesis presents three research manuscripts, each of which uses remote sensing and Geographical Information System methods to capture the dynamic nature of land along the Willamette River. In the first article, the river and its floodplain were mapped at four time periods, ranging from pre-settlement to modern day. The paper reports that the river system has been greatly simplified, and the floodplain has lost much of its original forest. An overlay technique was used to identify potential floodplain restoration sites. The second paper details the creation of a landcover map for the Willamette Valley, which shows that the largest portion of the floodplain is now in agriculture, with a significant amount in a built condition. The third manuscript outlines a methodology for detecting land cover change along the river during a twenty-year period that coincides with the implementation of the Willamette River Greenway, a land use designation designed to restrict riparian land conversion. It shows that regressive change is still occuring along the river, although not at the same rate as outside the greenway. The three papers lay the foundation for a future study to analyze the socioeconomic conditions which promote change.

LAND COVER CHANGE ALONG THE WILLAMETTE RIVER, OREGON

by

Doug R. Oetter

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented August 16, 2002
Commencement June 2003

Doctor of Philosophy thesis of Doug R. Oetter presented on August 16, 2002

APPROVED:

Major Professor, representing Geography

Chair of Department of Geosciences

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Doug R. Oetter, Author

ACKNOWLEDGEMENTS

Many important and wonderful people spent countless hours helping me learn how to become a researcher and encouraging me to stick with this thesis. I am greatly endebtted to the people I have worked with at the Corvallis Forestry Sciences Laboratory, notably Warren Cohen, Tom Maiersperger, and Linda Ashkenas, but also Sara Lipow, Robert Kennedy, Karin Fassnacht, Alissa Moses, Liz Gerson, George Lienkaemper, Theresa Valentine, Kelly Christiansen, and Sharon Clarke. And the list goes on and on.

I am forever grateful for the patience and advice of my major professor, Jon Kimerling, and my graduate committee: Bob Frenkel, Ron Doel, Stan Gregory, Aaron Wolf, and Kerry Ahearn. These people gave me everything I could have hoped for in making this thesis complete and competent. I deeply appreciate Keith Muckleston for getting me started on my program and seeing me through the tough times of the preliminary exams. I also thank Bob Beschta, Robert Miller, and Jim Morris for serving on my committee. I am indeed appreciative of all my professors at Oregon State University, especially Chris Gray, Bill Robbins, Steven Rubert, and Paul Farber for teaching me how the study of history is, and is not, like geography. And my thanks go to Joanne VanGeest, Melinda Peterson, and Theresa Belden of the Geosciences Department.

I could have not done this work without my peers. Many, many people shared their lives and thoughts with me, helping me to understand: Jill Saligoe-Simmel, Chris Oliver, Chris Purnell, Mario Hess, Colleen Kinney, Tracy Allen, Eric Larsen, David Shively, Diana Sinton, Bob Tuori, Neil Bursani, David Buchwalter, Christian Braudrich, Kelley Stearns, Eileen Helmer, Scott Bergen, Kitty Griswold, and all their fellow graduate students who finished, moved away, and left me here with nothing else to do but this thesis.

Also I want to acknowledge the many kind souls who endured me living in their space, from my very close friends Jennifer Whitewing, Katie Moore, Julie

Luetzelschwab, Rebecca Ward, Beth Lambert, Christine Reeh, Susanna Kummerow, Sybil Merrels, Kim Kittredge, Teri Lysak, and Julie Pendelton, to my housemates Pete Oboyski, Bob Tuori, Brian Norman, Scottie McKrell, John Hartigan, Amy Hartigan, Joe Lotrario, Tony Kaltenberg, Tamara Johnson, Stephanie McDowell, Todd Kagawa, Jeannine Beatrice, Steve Elliott, Eric Groth, Tom Delinks, Donna Grisham, Sadie Curry, Maureen Dailey, Jason Johannsen, Darrell Kaiser, Suzanne Lovelady, Jesus Anaya, Marya Gregory-Madsen, Jesse Howe, Zachariah English, Morgen Daniels, Megan Kleck, and Jack Lapham. There were many other people, both ultimate players and not, who kept me alive with their words and actions, for example my dear friends Maureen Duane, Judith Ingram, Eric Moore, Jesse Mitchell, Andy Neill, Tara Sechler, Rob Gandara, Tony Cheng, Mikell O'Mealy, Kris Whitbeck, Stirling Fox, Will Russell, and Andy Bluhm. And those of you in the Corvallis, Oregon, Pacific Northwest, and global Ultimate community know that there are far too many of you to mention, but I thank you all. There is one person who has recently come to know me and has seen me through the most difficult conclusion of this effort. For that I will forever love and cherish Katie Lynne Fisher.

And most importantly I thank my mother and father, George and Elisabeth Oetter, and my loving aunt, Sara Oetter, for keeping me secure and warm when I needed it most. My sister Beth Woodward has had a tremendous influence on this work, as did my dear deceased grandparents, Rudolph and Optye Oetter and George H. and Faye Sparks, who created the proper educational and emotional environment to see all this through.

CONTRIBUTION OF AUTHORS

For Chapter 2, there are three co-authors listed. Linda Ashkenas was instrumental in guiding the research behind this project, as well as performing much of the data creation and analysis required to accomplish such a tremendous task. She also offered many useful suggestions to my manuscript. Dr. Stan Gregory was the director and brains behind the entire project, and guided the research we completed. Paula Minear also worked laboriously on the construction of the Geographical Information Systems data.

For Chapter 3, there are four co-authors listed. Dr. Warren Cohen not only secured the funding for this research and had the faith to hire me as a Faculty Research Assistant, but also monitored my progress and taught me how to become a researcher. He improved the manuscript substantially by forcing me to tell the story in clear and complete language. Mercedes used her experience with us to capture the forested portion of the Willamette Valley, and offered the kindest words ever. Tom helped me understand the principles of remote sensing and was invaluable in discussions on our mapping technique. Robert, also, never lost enthusiasm for my work and helped out immensely by writing an Interactive Data Language program that helped georectify our TM images. Each of the co-authors offered editorial comments on the manuscript.

TABLE OF CONTENTS

CHAPTER 1. PREFACE 1

INTRODUCTION 1

RIVER SYSTEMS AND RIPARIAN CONSERVATION 3

RIPARIAN GREENWAYS 5

WILLAMETTE RIVER HISTORY 8

THE WILLAMETTE RIVER GREENWAY 13

LAND USE PLANNING 18

EVALUATION OF POLICY IMPLEMENTATION 20

EVALUATION OF LAND USE POLICIES AND LANDSCAPE CHANGE 24

SPATIAL METHODS FOR LAND COVER CHANGE ANALYSIS 26

SPATIAL METHODS FOR RIPARIAN CHANGE ASSESSMENT 29

OVERVIEW 32

REFERENCES 34

CHAPTER 2. GIS METHODOLOGY FOR CHARACTERIZING HISTORICAL CONDITIONS OF THE WILLAMETTE RIVER FLOODPLAIN, OREGON 49

ABSTRACT 50

INTRODUCTION 51

Study area 52
Objectives 55

METHODS 55

Generation of floodplain extent 56
Channel mapping 57

TABLE OF CONTENTS (continued)

Floodplain vegetation mapping 60

RESULTS 62

DISCUSSION AND CONCLUSIONS 64

ACKNOWLEDGEMENTS 69

REFERENCES 70

CHAPTER 3. LAND COVER MAPPING IN AN AGRICULTURAL SETTING USING MULTI-SEASONAL THEMATIC MAPPER DATA 75

ABSTRACT 76

INTRODUCTION 77

METHODS 82

Study area 82
Remotely sensed imagery and preprocessing 84
Ground and airphoto reference data 87
Image analysis 93
Map generation and error characterization 97

RESULTS 97

Radiometric normalization 97
FSA slide interpretation 98
Classification 99
Willamette Valley land cover map 101

DISCUSSION 104

Desired versus mapped classes 104
Multi-seasonal Tasseled Cap trajectories 108
Using the map 110

ACKNOWLEDGEMENTS 112

REFERENCES 112

TABLE OF CONTENTS (continued)

CHAPTER 4. RIPARIAN LAND COVER CHANGE DETECTION ALONG THE WILLAMETTE RIVER, OREGON 117

ABSTRACT 118

INTRODUCTION 119

Study area 120
Objectives 123

METHODS 124

Reference photos and ancillary data 124
Study area delineation 126
Image acquisition and pre-processing 129
Change detection 130
Accuracy assessment 137

RESULTS 138

DISCUSSION 141

Landscape change along the Willamette River 141
Change detection methods 143
Summary 147

ACKNOWLEDGEMENTS 148

REFERENCES 149

CHAPTER 5. SUMMARY AND CONCLUSION 156

SUMMARY OF FINDINGS 156

FUTURE RESEARCH 158

CONCLUSION 160

BIBLIOGRAPHY 163

LIST OF FIGURES

Figure		Page
1.1	Willamette River Basin in Western Oregon	9
1.2	Willamette River	12
1.3	Willamette River Greenway major forces and interrelationships	17
2.1	Creation of the slices analysis coverage from four flood extent maps for multiple years is shown for the Willamette River basin in northwest Oregon	53
2.2	Development of channel maps from different sources of spatial data for 1850, 1895, 1932, and 1995.	58
2.3	Derivation of channel and forest bank complexity attributes attached to the thalweg	60
3.1	Willamette River Basin in Western Oregon	79
3.2	Photographs that exempify Willamette Valley landscapes	85
3.3	Landsat Thematic Mapper images acquired in 1992	86
3.4	Ground reference points for forest and non-forest sites	91
3.5	Flow chart of the image processing steps	95
3.6	Spectral signature means with ellipses drawn at one standard deviation	96
3.7	1992 20-class land cover map of the Willamette Valley	105
4.1.	The Willamette River Basin in northwest Oregon.	121
4.2	Three dates of aerial photography ground reference used for training and testing the change detection procedure, at the confluence of the Willamette River with the Multnomah Channel north of Portland	125
4.3	The Willamette River Greenway and the study area boundaries in the Willamette Valley	128

LIST OF FIGURES (continued)

Figure Page

4.4 Process schematic of change detection technique.......................................131

4.5 Feature space images of Template 3 for three dates with a) full complement of training polygons, and b) merged land cover signatures with 1 standard deviation ellipses...135

LIST OF TABLES

Table		Page
1.1	Stages of the Willamette River as a resource	10
1.2	Local jurisdictions along the Willamette River Greenway	15
2.1	Reach and total areas (ha) of seven different spatial analysis containers within the study area	62
2.2	Summary of lengths and areas for channels and islands in the Willamette floodplain from 1850-1995	65
2.3	Summary of changes in channel characteristics for the Willamette River from 1850-1995	66
2.4	Summary of changes in riparian vegetation (up to 120 m from riverbank) for the Willamette floodplain from 1850-1995.	67
3.1	Pacific Northwest Ecosystem Research Consortium (PNW-ERC) projects	78
3.2	Categorical list of the classes desired by the PNW-ERC	81
3.3	Ground reference data	89
3.4	Farm Service Agency crop interpretation codes for non-forest	92
3.5	Radiometric normalization models	98
3.6	Photointerpretation error matrix	100
3.7	Final land cover classes for Willamette Valley study area	102
3.8	Error matrix for land cover classes	103
3.9	Closed conifer forest age error matrix	104
3.10	Final map status of the classes desired by the PNW-ERC	107
4.1	Pre-European settlement and c. 1990 land cover within the study area	129
4.2	Landsat images used in the study.	130

LIST OF TABLES (continued)

Table Page

4.3 Training polygons used to perform supervised classification. 134

4.4 Land cover change results within the study area for three change maps. ... 139

4.5 Land cover change results (1970's-90's) grouped by study area type............ 140

4.6 Accuracy assessment of a) 1970's-1980's change map; b) 1980's-1990's change map; and c) 1970's-1990's change map. 142

4.7 Comparison of Landsat-derived change with an earlier study which used aerial photography as reference.. 144

LAND COVER CHANGE ALONG THE WILLAMETTE RIVER, OREGON

CHAPTER 1. PREFACE

INTRODUCTION

One of the greatest challenges in geography is the conceptualization of dynamic human systems. Neither humans nor their environment stand in stasis long enough to provide an effective glimpse of their myriad relationships. This is perhaps the key paradox of the man-land tradition of geography (Pattison 1964), which explores both the influence of the landscape on the development of human societies and the expression of those societies on the natural world (Marsh 1864; Sauer 1956; Thomas 1956; Goudie 1994). The traditional objectivist approach to the scientific method does not work well in this arena, as the Earth is not a closed system which the researcher can manipulate using laboratory methods (Guelke 1971). Instead, the geographer must use strong inference to make generalizations pertaining to the forces of nature and society which shape the world around us (Platt 1964). If patterns can be discovered, the conscientious geographer then has the unique opportunity to present findings both to an academic society and the community at large, so that the knowledge can be developed into a strategy for the improvement of both humans and their environment (Stoddart 1986). This is, after all, perhaps the strongest motivation behind modern geography in a world of impending environmental stress (Johnston 1993).

The tradition of resource geography, in particular, has its roots in both the natural world (geomorphology, climatology, hydrology, etc.) and human activities which employ or respond to the environment (hazards and risk assessment, landscape evaluation, regional planning, etc.) (Mitchell 1989). In this pursuit, the geographer's task is to both describe the physical landscape and relate it to the human infrastructure (physical and metaphysical) which has come to be associated with that landscape. The latter half of the 20th century saw a dramatic increase in academic attention to resource geography, as concerns over resource supply and population growth prodded geographers to shape their research to serve the public good (Chorley 1969; Baumann and Dworkin 1978; Marcus 1979). There are a wide variety of new approaches that link human activites and the environment over time, in an effort to explain history and ecology as codeveloping disciplines (White 1995; Cronon 1996; Russell 1997). Presently, resource geography entails a wide spectrum of academic pursuits, but few among these are as challenging and exciting as the efforts to restore and protect the nation's rivers and other surface water supplies (White 1977; Muckleston 1990; Platt 1992).

In his recent presidential address to the Association of American Geographers, Graf (2001) suggested a method of resource geography in his report on the state of America's river systems. He detailed not only the natural context of rivers, but also the human response, especially damming and channelization of rivers. Graf described the tragic history of America's over-management of rivers, and then made specific recommendations for scientists and policy makers. Among these is to "preserve as much as possible of the tiny amount of remaining rivers that is in a pretechnological condition" (Graf 2001: 24). In his address, and by his choice of a research topic, Graf defended the role of a resource geographer to conceptualize the diverse interactions between the physical environment and human activities, and to offer commentary on what has been done wrong and what should be done better. That is the essence of resource geography applied in modern times to a very important topic.

My overall objective is to characterize a dynamic physical system (land along the Willamette River) in response to a complex human infrastructure (land use change), and to quantify past change and discuss what might be improved upon in the future.

RIVER SYSTEMS AND RIPARIAN CONSERVATION

Rivers are complex physical systems, governed by numerous interactions between the atmosphere, lithosphere, and hydrosphere. The presence of life forms, especially humans, alter these systems even further. Dams, levees, ditches, and diversions further fragment river systems which are already quite diverse in their natural state. Yet in spite of the countless unique features of a river, the system may still be considered an integrated and complete whole (Newson 1992a; White 1995). In certain situations, it is even possible to develop conceptual models of river systems as continuous units. The river continuum concept is one such model that depicts the biological productivity of a river from headwaters to sea as a progression of environmental changes, all linked to the physical characteristics of the river (Vannote et al. 1980). Other conceptualizations range from open channel flow to historical landscape-based approaches which model the river as a dominant feature within much larger terrestrial and socioeconomic systems (Minshall 1988; NRC-CRAE 1992).

Perhaps the most confounding aspect of a riverine system is the unavoidable linkage between a surface water body and its surrounding landscape. Dissolved sediments, nutrients and pollutants from the land are frequently destined to reach a surface water body at some point on the downstream migration toward the sea. Numerous studies have demonstrated that land disturbances have a significant effect on water quality and quantity downstream (Likens and Bormann 1974; Karr and Schlosser 1978; Swanson et al. 1982; Peterjohn and Correll 1984; Gregory et al. 1991; Roth et al. 1996). Chauvet and DéCamps (1989) characterize three lateral interactions along a fluvial landscape: 1) longitudinal along the tributary stream network to the estuary, 2) vertical between the river and the adjacent groundwater, and 3) lateral within the floodplain. The third type of interaction best describes the riparian zone, which is the ecotone between land and water. Within this area, biological diversity is high, and the interchange of energy and matter between terrestrial and lotic systems is maximized. In fact, the health of a riparian system can often be used to estimate the condition of the entire watershed, since riparian interactions play such an important role in determining river water quality (LaFayette and DeBano 1990). The riparian buffer acts as an important filter for nutrients and pollutants migrating toward the stream, and the ecological corridors alongside rivers are critical natural habitat for wildlife dispersal and refuge (Odum 1978; Lowrance et al. 1984; Malanson 1993).

The nature of rivers is to change, and the constant spatial flux of watercourses further compounds the difficulty of studying them. Human influences, such as impoundments and artificial channels, have altered riverine systems dramatically in the past few centuries (Palmer 1986; Petts et al. 1989; Squires 1992). Outside the main river channel, humans have removed riparian forests and drained major wetlands (Décamps et al. 1988). These practices have produced vast and disturbing cumulative effects, resulting in the loss of innumerable ecological services ordinarily provided by natural processes, "including moderation of downstream flooding, maintenance of good water quality, and provision of diverse habitats for wildlife" (Gosselink et al. 1990: 588). In order to prevent the environmental degradation of riverine systems, it is necessary to employ broad scale analytical techniques which can address changes in both time and space (Petts et al. 1989; Allan and Flecker 1993).

For many reasons, including the economic and ecologic values of rivers, there has been a recent shift in societal values towards preservation of rivers in their natural state and restoration of degraded and polluted rivers (NRC-CRAE 1992; Rapp 1997; Graf 2001). River protection activists have developed several methods of protecting rivers from abuse and degradation, ranging from enforcement of the Clean Water Act to the purchase of riparian easements (Bolling 1994). River conservation encompasses many different strategies for both improving the condition of the river and preserving the adjacent lands. Geographers and other scientists play an important role in river conservation efforts by describing the landscape-scale functions of a natural river ecosystem and evaluating the present condition of threatened rivers (Doppelt 1993; Malanson 1993; Bayley 1995; Leopold 1997; Giller and Malmqvist 1998).

Part of the motivation behind the study of river ecology and the practice of riparian conservation is the idea that a river represents a pure natural form, and in spite of human advancements in putting rivers to work, the highest use of a river may come from its natural state. This sentiment was captured by Leopold: "a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community" (Leopold 1966: 262), and he suggests a landscape ecology tenet that ecological integrity is "characterized by 1) natural levels of plant (primary) productivity, 2) a high level of native biological diversity, 3) natural (usually very low) rates of soil erosion and nutrient loss, and 4) clean water and healthy aquatic communities" (Thorne 1993: 24). It is no wonder, then, that the techniques of river conservation are usually just efforts to return the river to some version of its 'natural state,' which implies a river without dams, diversions, channelization, or excessive streamside erosion (Bolling 1994). One methodological approach, river restoration, implies "the reestablishment of predisturbance aquatic functions and related physical, chemical, and biological characteristics" (NRC-CRAE 1992: 17). This approach can require "reconstruction of antecedent physical conditions, chemical adjustment of the soil and water, and biological manipulation" (p. 18). A more ambitious river conservation method is full preservation of the river course and its floodplain in its natural state, either through fee-simple acquisition or legislative mandate, such as the Wild and Scenic Rivers Act.

Because preservation of a river segment without any human development or amenities seems draconian to most (Boon 1992), a more common conservation tool is the designation of protected riparian corridors, or greenways. While greenways are merely one of the dozen or more approaches to river conservation, they provide a wide offering of economic and ecologic benefits and also appeal to a growing faction of riverine recreationists (Grove 1990).

RIPARIAN GREENWAYS

A greenway is a linear park or preserve designed to protect open space and ecological habitat while providing public recreation opportunities. While not confined to river corridors, greenways have been lauded by river conservationists as an ideal method of preserving riparian habitat and abating flood damage. Several books and articles have been written in the last few years detailing the greenway method of river conservation and promoting their application to urban and rural rivers alike (Little 1990; Flink 1993; Schwarz 1993; Smith and Hellmund 1993; NPS 1995; Fabos and Ahern 1996).

The idea behind a greenway is to create a linear park or trail which spreads its benefits wide and far. When Frederick Law Olmsted and others envisioned linear parks in the late 1800's, they surely thought first of using greenways to create a system of scenic transportation routes (Little 1990). Olmsted created a connected system of parks for Brooklyn, Boston, and Seattle. His ideas carried on with the works of Robert Moses, the great public works builder of New York City, and Benton MacKaye, inventor of the Appalachian Trail. Through the works of such visionaries as Ian McHarg, Philip Lewis, and William Whyte, greenway and beltway designs have become synonymous with post-modern urban design, as natural methods of relieving urban sprawl while connecting the few remaining pristine enclaves. Greenway plans abound today, from small creeks to large rivers. The proponents tout the multitude of benefits for recreation, for nature, and for the economy (Schwarz 1993). While many of their arguments are convincing and ring true, there has been scant policy evaluation of the greenway implementation process (Lindsey et al. 2001).

The prime social benefits of greenway development tend to come from the enhanced recreational opportunities greenways provide (Furuseth and Altman 1991). Biking, hiking, picnicking, boating, and just lazing on a Sunday afternoon are all activities made possible by greenways. Other social benefits include the aesthetic visual appeal of landscapes and the presence of a peaceful transportation corridor to placate the commute to work (Smith 1993). In addition to these values, riparian greenways are also said to improve local economies. The National Park Services Rivers, Trails and Conservation Assistance program lists these economic benefits derived from greenways: increase in real property values, commercial activities, increased tourism, citizen and government expenditures, corporate relocation and retention, and public cost reduction (NPS 1995). Many greenways have been built following floods that caused tremendous property damage; the present greenways help abate flood damage (Little 1990).

Recently, the ecological benefits of greenways have received a great deal of attention, as ecologists and planners seek to protect wildlife habitat and natural ecosystem functions while realizing the demands of a growing and more recreational human population. Labaree (1992) offers that greenways provide habitat, and simultaneously act as environmental conduits, barriers, filters, sources, and sinks. Greenways address the regional concerns of a loss of natural space, the fragmentation of natural ecosystems, the degradation of water resources, and a diminished ability of nature to respond to ecological change (Labaree 1992). The full ecological benefits of greenways can include ground water filtration, sediment retention, wildlife migration corridors, water quality improvement, hydrologic regulation, and many more (Binford and Buchenau 1993).

It is no wonder, then, that riparian greenways are a recommended method for river conservation. The greenway "objective is a plan which can ... be reviewed by the public and sold to business and government as a blueprint for restoring and protecting the river corridor" (Bolling 1994: 189). Greenways are thought to preserve the natural ecological function of a riparian zone, allowing the river processes to occur with minimal interference from human activities, and in fact serving as an important component for efforts to preserve regional biodiversity (Naiman et al. 1993). At the same time, greenways can be difficult to institute, requiring "the cooperation of such a diverse variety of interests that a consensus is often difficult and compromise of environmental values a frequent concern" (Bolling 1994: 190).

A leading example of a riverine greenway is the Willamette River Greenway (WRG) in northwest Oregon. According to Little (1990), the WRG may be the first legal use of the word 'greenway' in the country. It has been lauded as a nationally important land use mechanism which has "made a profound difference in maintaining natural processes more or less intact along the corridor" (Little 1990: 109-110). Before outlining the history of the WRG, a brief introduction to the Willamette River is appropriate.

WILLAMETTE RIVER HISTORY

The Willamette River drains over 11,250 square miles (29,700 km^2) in western Oregon (Figure 1.1). Most of this watershed is forested (62%), with a large agricultural component (33%) and a relatively small urban area (5%). The river is over 200 miles (320 km) long, from the Dexter dam on the Middle Fork to the confluence with the Columbia River north of Portland. Its average flow at Salem is about 23,000 cfs (17 MAF/yr, 650,000 l/s). The river moves through three distinct hydrologic reaches: a shallow, fast moving channel above Newberg; a deep pool from there to just above Willamette Falls; and a deep tidal reach through Portland to the Columbia River. Most of the river's flow comes from winter and spring rains, with a small contribution from snowmelt in the high Cascades (Muckleston 1986).

The modern Willamette River has been drastically changed by human activity, reflecting various economic demands over the course of history (Corning 1973; Muckleston 1986; Boag 1992; Robbins 1997, Hulse et al. 2002). During the early settlement stage in the middle to late 1800's (Table 1.1), the river was cleared of snags and channeled to allow for riverboat traffic (Sedell and Froggatt 1984; Benner and Sedell 1994). The end of the second stage of Willamette River history saw railroads replace riverboats as the primary means of getting agricultural goods to market. As farms developed throughout the valley, initially at the fringe of the upland prairies and then spreading toward the river, native vegetation was removed and the floodplain was drained (Johannessen et al. 1970; Towle 1982; Boag 1992; Bunting 1997; Robbins 1997). In the twentieth century, the river became an important vehicle for waste removal, and its water quality suffered from excessive pollutants (Leland et al. 1997). After World War II, several dams were constructed for flood control and hydropower production, and their summertime releases helped dilute effluents and improve water quality (Gleeson 1972). There are fourteen water storage projects in the basin upstream from Willamette Falls (Figure 1.1). In addition, following a devastating flood in 1964, the Army Corps of Engineers (ACOE) augmented streambank stabilization along the river. The cumulative effect of channelization, damming, levee construction, and other human alterations has been to create a "Willamette Conduit" (Frenkel et al. 1996).

Figure 1.1. Willamette River Basin in Western Oregon. Major cities and reservoirs are shown.

Table 1.1. Stages of the Willamette River as a resource (Muckleston 1986: 49). Principal uses are underlined.

Stage I (< 1840)	**Stage II (1840-1870)**	**Stage III (1870-1938)**	**Stage IV (> 1938)**
Indigenous Occupance and Fur Trade	Early Settlement	Urbanization and Industrialization	Modern Urban-Industrial
Fish and Wildife Habitat	Transport	Waste Carriage	Waste Carriage – Treated and Diluted
A. Indigenous - Fish	A. Animate Energy Current	Industrial	Industrial
B. Trapping - Fur Bearers	B. Steam Navigation	Municipal	Municipal
Transport	Power (Mechanical)	Hydropower	Recreation
Other Water-Derived Services of the Period	Waste Carriage		Fish & Wildlife Habitat
	Fish Habitat, below Willamette Falls		Preservation in Natural State
			Irrigation
			Hydropower

By the time Oregon entered its renaissance period in the 1960's, three major changes had altered the Willamette River landscape. First, it had been known for some time that the river was foul and unfit for many human uses. Despite precursory sanitation control measures, initiated as early as the 1930's, pulp mill and municipal sewage effluents had contaminated the river to the point where the Portland harbor suffocated salmon attempting to make their upstream migration. The Governor's assistant for natural resources acknowledged that the Willamette was one of the most polluted rivers in the nation (Starbird 1972). The problem was remedied only after aggressive policies solidified public support and funded efforts to force industries and cities to treat their waste effluent. The construction of two large reservoirs on the upper Willamette in the 1950's allowed the ACOE to increase summer flows and provide pollution dilution. By 1966, regulations established by the State Sanitary

Authority had achieved secondary treatment throughout the basin, and the river showed remarkable improvement. The attention on the cleanup effort fueled a new public demand for river recreation, which eventually led to the appointment of the Willamette Recreational Greenway Committee by Governor Tom McCall in 1967 (Bauer 1980).

As Governor McCall envisioned it, the formation of a recreational park along the 205 miles of river from above Eugene to the Columbia River would provide public access and also help stem rapid urbanization, the second major alteration to the Willamette landscape. McCall echoed the concerns of professional planners who feared uncontrolled urban growth and its undesirable effects on natural systems and the human quality of life (Jensen 1964). By restricting development along the river, the state could contain suburbanization to more suitable environments and reduce the risks of flood damage while protecting valuable natural habitat and providing recreation opportunities. Government attitudes toward land use had been historically oriented toward increased settlement (Robbins 1974), but with the advance of planning methods (McHarg 1971), concerns emerged to induce Oregon to seek restrictions on urban growth (Miniszewski 1979).

The third major change in the structure of the Willamette landscape was the result of over a hundred years of human tinkering with the natural functions of the river. Especially due to result of navigation enhancement and flood control efforts, the riparian ecosystem had been drastically altered from its pre-settlement condition. The resultant landscape was typically sterile and devoid of natural influences. Farmers had encroached right up to the riverbank in many cases, as had sand and gravel operations (Figure 1.2). Changes in watershed landscapes created changes in the river itself, especially in the ecotone, or region along the river's banks. Landscape ecologists refer to the 'edge effect' as the boundary where increased biodiversity is caused by two different ecosystems adjoining. Where an ecotone is caused by a linear feature, it becomes a corridor, which in nature provides for wildlife migration and increased habitat (Forman and Godron 1986). Along the Willamette, much of the edge effect was damaged by riparian forest conversion and channel alteration (Benner and Sedell 1994; Gutowsky and Jones 2000), which subsequently led to reduced capabilities of the river system for watershed protection and flood mitigation (Frenkel et al. 1996). In a nine-year period from 1972 to 1981, 12.6 percent (294 hectares) of the natural vegetation cover along the Willamette in Benton and Linn counties was removed, and the land was converted to agriculture, sand and gravel operations, or urban development (Frenkel et al. 1983). This type of landscape alteration generally reduces the natural function of riparian zones, increasing sedimentation, flooding, and fish and wildlife impacts.

Figure 1.2. Willamette River. This photo was taken looking west across the river at Weston Bend, near Dayton. Horseshoe Lake, a remnant oxbow pond, is visible in the center, and Dayton is west of it. The riparian vegetation along the river is often constricted by agricultural development. Remnant forest stands are connected by the river, and otherwise separated from each other (photo courtesy of Oregon State University Department of Fish and Wildlife; date unknown).

THE WILLAMETTE RIVER GREENWAY

Primarily in response to the loss of valuable farmland to urban sprawl, the Oregon State Legislature passed Senate Bill 100 in 1973 to create the Land Conservation and Development Commission (LCDC) within the Department of Land Conservation and Development (DLCD). The mission of the DLCD was to assist and guide the state's 241 cities and 36 counties in developing comprehensive land use plans (Abbott et al. 1994). Guided by environmental and economic concerns relating to land conversion, the legislature wrote into law the ability of local governments to disapprove certain private intentions that would have damaging effects on the public good (Rohse 1987). One of the most intriguing applications of this law came with the Willamette River.

To set the stage, the Willamette River was a major campaign issue for both gubernatorial candidates in the 1966 election (Bauer 1980). After Republican Tom McCall won, he set out to fashion a recreational greenway along the river as promised during the campaign. The legislature passed the Willamette River Park System Act in 1967 which authorized the State Highway Commission to apply funds to purchase land along the river for recreational uses, especially boating, hiking, and public access. The state initially funded $800,000 to purchase these lands, and later received $1.6 million from federal Land and Water Conservation Funds (L&WCF). But they were not able to buy the most desired lands because the private landowners were unwilling sellers, so in 1971, the Willamette River Corridor Program (WRCP) was created to spend an additional $5 million L&WCF allocation. The WRCP was found to have the power of eminent domain, and could therefore condemn private property in order to acquire land for the greenway program. This development, especially in the hands of the puissant Department of Transportation (DOT, the former Highway Commission), frightened farmers along the river to the extent that they formed the Willamette River Frontage Owner's Association to block proposed land condemnations. The result of their efforts was new legislation, the Willamette River Greenway Act (WRGA), which was signed into law on 21 July 1973.

The WRGA created the foundation for statewide land use planning along the Willamette River, even though that was not the immediate intent of its proponents (Bauer 1980). In a sense, the farmers who supported the bill in order to keep the DOT away from their land provoked another type of problem: land use planning as determined by the newly formed DLCD. This resulted from a stipulation that DLCD must approve the greenway plan as proposed by DOT, as a safeguard against a cavalier DOT seizure of private lands by unilateral decree. The DOT spent close to $200,000 composing their plan (ODOT 1974), which was a detailed assessment of existing riparian conditions and river functions. It partitioned land into river, urban, farm, and non-farm categories, and suggested boundaries for the proposed greenway. The plan was written by a leading San Francisco consulting firm, which employed McHargian overlay methods and elaborate assessment matrices (McHarg 1971), and conducted numerous public hearings to evaluate the physical and institutional attributes of the greenway proposal.

Unfortunately, perhaps, the consultant's plan was never used. A new Governor, Democrat Robert Straub (who popularized a recreational greenway plan when he ran against McCall in 1966), was elected in 1974. Straub strongly disliked the 1973 Greenway Act and the DOT proposal. He believed that the act prohibited state acquisition of undeveloped land and failed to prevent development along the river. Straub saw to it that the DLCD turned down the DOT plan and instead adopted their Alternative 6, which created a Statewide Greenway Planning Goal (Goal #15) within the DLCD statewide planning structure under the authority of LCDC Chairman L. B. Day (Bauer 1980).

Goal #15 was devised "to protect, conserve, enhance and maintain the natural, scenic, historical, agricultural, economic and recreational qualities of lands along the Willamette River as the Willamette River Greenway" (OLCDC 1990: 13). The new self-appointed role of the DLCD, which came at the expense of DOT's authority, changed the greenway concept in several ways. First, it switched the focus of the project from creating recreation opportunities to conserving land for environmental and economic (land use) reasons. Instead of relying on acquisition, the DLCD employed local police power to enforce its objectives. This allowed the boundaries of the proposed greenway to be attained automatically without any further acquisition. Finally, it placed the decisions concerning use of the greenway in the hands of local governments (Table 1.2), as they were now required to include Goal #15 in their comprehensive land use plans (Bauer 1980). The DOT still had to come up with a management plan for state greenway lands, which they did in 1976 (OSPRB 1976).

Table 1.2. Local jurisdictions along the Willamette River Greenway.

County	City
Benton	Albany
	Corvallis
Clackamas	Gladstone
	Lake Oswego
	Milwaukie
	Oregon City
	West Linn
	Wilsonville
Columbia	Saint Helens
Lane	Cottage Grove
	Eugene
	Springfield
Linn	Albany
	Corvallis
	Harrisburg
	Millersburg
Marion	Keizer
	Salem
Multnomah	Portland
Polk	Independence
	Salem
Yamhill	Dundee

The importance of Goal #15 was the application of Oregon's land use law to a unique and natural feature of special significance. The goal was written into the comprehensive plans for all eight counties along the greenway. Counties were required to conduct inventories, establish an administrative boundary, and develop implementation goals. They were asked to respond to existing and future population demands on the river, and motivate a public re-orientation to the river as a recreational resource. The local plans were specifically required to address historical sites, land use patterns, soil suitability, timber resources, fisheries and wildlife, flooding, public access, and proposed acquisition sites (Miniszewski 1979).

Perhaps to avoid further controversy, state funding to acquire more greenway lands tapered off after 1976. Following that was the restriction of federal L&WCF money and Oregon gas tax revenues in the early 1980's. Since that time, acquisition and development of state lands within the greenway has been minimal (Nabeta and Payne 1991). Goal #15 remains an important part of land use plans in the valley, and controversial WRG development issues frequently arise (Munch1984). Some authors have questioned its effectiveness, and believe that the natural qualities along the river have not improved as a result of Goal #15 (Frenkel et al. 1984; Frenkel et al. 1996). While many individuals, both inside and outside of state government, have worked diligently to promote the resurrection of the greenway ideal, funding problems and the complex nature of the program itself (Figure 1.3) have stifled a resurgence to date (McPherson 1992).

Present-day impacts on the Willamette River natural landscape include sand and gravel mining, agricultural and timber conversion, rural residential development, and urbanization. It is important to note that Goal #15 does not specifically restrict many important land use conversions. Many types of economic development, such as dock building, clear cutting of forests, and rebuilding of existing structures, are allowed with only minimal review. The essence of the planning goal is to direct local land use zoning boards to maintain and preserve the scenic and natural qualities of the Willamette riverfront, however their decisions are liable to local politics and available

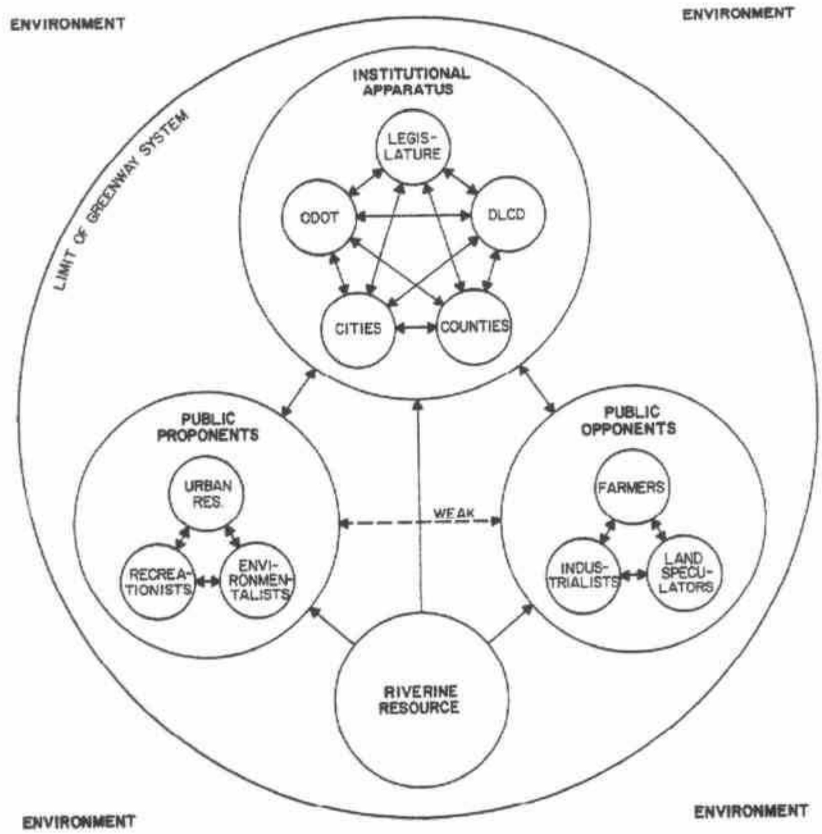

Figure 1.3. Willamette River Greenway major forces and interrelationships (from Bauer 1980: 195). This diagram traces the interactions among the greenway program participants c. 1980, however the present situation has not changed a great deal, except that OSPRD is now its own agency, no longer part of ODOT.

exemptions. Of particular concern to some is the lack of direct protection of riparian vegetation and other natural resource values. Forests on farmland, for example, are exempt if the affected area is less than 20 acres. In addition, deposits of sand and gravel aggregate are routinely allowed under the plan when they are economically feasible and permitted by Oregon Department of State Lands.

The current plan for the greenway, as envisioned by the Oregon State Parks and Recreation Department (OSPRD), is to stay involved with greenway development on the Willamette in the shadow of an ever-diminishing state budget for natural resource development (Nabeta and Payne 1991; Miniszewski and Nabeta

1993). At best, OSPRD is now a watchdog, attempting to hold onto the lands it acquired in the early 1970's while providing recreational opportunities at a minimum of expense. On another note, however, the general level of public interest in the Willamette River has risen, spurred by attention to the 1996 floods and the efforts of citizen groups (Willamette Riverkeeper 1996). In particular, efforts are now underway to purchase land within the Willamette River floodway for flood control mitigation, simultaneously providing floodwater retention and wildlife protection areas (River Network 1995; Gregory 1999). Future plans for the development and protection of the Willamette River landscape may rely upon the WRG. The role that the greenway will play depends in some part upon the success it has had since its inception.

LAND USE PLANNING

Part of the reason that the Willamette River Greenway became a land use planning goal under the DLCD was the existence of a strong state-wide land use planning system, established in Oregon in 1973 (Little 1974; Rohse 1987). Rather than scrap the greenway program completely when objections blocked the acquisition of land for recreational benefits, the legislature opted to incorporate the greenway concept into the existing legal structure (Bauer 1980). Since the precedent for police power over land development had already been established and defended by court action, greenway supporters in the legislature hoped that Goal #15 would prevent haphazard development along the Willamette River while protecting farmlands.

The use of land use control policies to restrict undesirable development had been well established by the mid-1970's (Mather 1984). States have typically granted police power to local cities and counties to allow them to promote sound growth and to protect the rights of landowners from undesirable off-site effects (Platt 1996). Oregon allowed cities the authority to enforce land use plans as early as 1919, and Portland initiated citywide zoning in 1924 (Abbott et al. 1994). The unique aspect of Senate Bill 100, which established the Oregon state-wide planning law in 1973, is that it compels each local jurisdiction in the state (36 counties, 241 cities and towns, and 1 metropolitan service district) to write a comprehensive plan for development, which then becomes a binding legal document in future land use issues. Once the comprehensive plan is adopted by the LCDC, it acts as a type of constitution for local planning authorities as well as citizens (Gustafson et al. 1982). Rather than watching each jurisdiction establish new precedents every new land use decision, the Oregon program builds on the framework of a local plan which has been drafted to effect the 19 statewide land use planning goals, one of which (Goal #15) specifically regulates development within the Willamette River Greenway (Abbott et al. 1994).

Much of the incentive behind Oregon's land use law came from a rapidly expanding urban population in the 1960's. According to Abbott et al. (1994: xii) "Willamette Valley residents from Eugene to Portland viewed sprawl … as an environmental disaster that wasted irreplaceable scenery, farm land, timber, and energy. Metropolitan growth was explicitly associated with the painful example of southern California." The Oregon planning law was crafted to preserve the unique rural and natural features of the Oregon landscape that would be threatened by unconstrained urban expansion. The lawmakers were especially concerned with farmland in the Willamette Valley, which accounts for almost half of the state's agricultural product. The designation of Exclusive Farm Use (EFU) zones and Urban Growth Boundaries (UGBs) was intended to keep suburban sprawl from forcing farmers off their land due to property value increases (Pease 1982). In addition, the LCDC identified several other concerns in the statewide planning goals, such as scenic and historic areas, areas subject to natural disasters, energy conservation, estuarine resources, and coastal shore lands (OLCDC 1990).

The Oregon land use plan has received national attention due to its comprehensive and multi-tiered approach. It is a significant plan because it mandates comprehensive plans which must address statewide goals designed to maintain environmental standards. It has been in place for almost thirty years now, and the pressures of urbanization and land use conversion have continued to develop over that time (Abbott et al. 1994). It is a useful academic exercise, in a situation such as this, to examine the effectiveness of a policy's implementation, both as a critique of the past and as a guide to the future.

EVALUATION OF POLICY IMPLEMENTATION

Land use regulations and other public policies are extremely expensive to put in place, both for government and the public. That is one important reason that it is a good idea to ascertain whether or not they work. The academic approach of conducting a policy implementation is known as 'evaluation.' Broadly defined, a policy evaluation is a "systematic inquiry that describes and explains the policies' and programs' operations, effects, justifications, and social implications. The ultimate goal of evaluation is social betterment, to which evaluation can contribute by assisting democratic institutions to better select, oversee, improve, and make sense of social programs and policies" (Mark et al. 2000: 3).

The field of policy implementation studies has been active for some time, applied effectively to the large-scale national programs of economic development, health care, energy conservation, and coastal zoning in the 1970's (Pressman and Wildavsky 1974; Harrald et al. 1979; Rossi et al. 1979). One popular framework for evaluating policy implementation was offered by Mazmanian and Sabatier (1981). Their attention was given to the stated policy goals and objectives, along with the theories, structures, and actors who present and effect those goals and objectives. In this manner, it was possible to construct measures or indicators which could characterize the effectiveness of policy implementation. The framework has been applied to Oregon's Coastal Zone Management Act (Good 1992), old-growth forest harvesting (Wilson 1994), and energy conservation plans (Mullens 1995).

There are many methods of evaluating public policy and formulating measures of their successes. Nagel (1990) suggests that at the base of these methods is an evaluation of the social costs and benefits of a particular policy, especially with regard to issues of effectiveness, efficiency, and equity. Mazmanian and Sabatier (1981) focused their work more on the implementation of a statutory policy, with special attention to the "tractability" of the problem, the ability of the governing body to legislate its solution, and other external variables affecting implementation. In both of these approaches, the evaluators must tally the responses of a variety of interest groups with regard to the policy implementation. Mark et al. (2000: 15) describe four 'inquiry modes' for evaluation practice:

1. Description: methods used to measure events or experiences, such as client characteristics, services delivered, resources, or client's standing on potential outcome variables;
2. Classification: methods used for grouping and for investigating the underlying structures of things, such as the development or application of a taxonomy of program subtypes;
3. Causal analysis: methods used to explore and test causal relationships or to study the mechanisms through which effects occur; and
4. Values inquiry: methods used to model natural valuation processes, assess existing values, or dissect value positions using formal or critical analysis.

Their methodology is guided by 'commonsense realism,' the tenet that experiences and events are initiated by actual mechanisms and structures, and that the results of those events can be sensed, either qualitatively or quantitatively. The authors use this framework to demonstrate the four methods of evaluation in a wide variety of applications, from testing job performance and preschool development to AIDS care and traffic stops.

Most of the traditional tools for policy evaluation have been developed from the methods of political science and public administration (Mazmanian and Sabatier 1981; Nagel 1990). While those tools may be effective for characterizing and comprehending the complex political structures associated with most important public policies, they are not as useful for measuring landscape responses to land use policies. In terms of the four general evaluation methods outlined by Mark et al. (2000) above, description and causal analysis are most applicable to land use implementation studies. Nelson and Moore (1996) identified several problems associated with evaluating land use policies: 1) there is no 'control group' which would indicate what would have happened without growth management; 2) planning requires long time periods to implement, and it may be difficult to detect short-term responses; 3) cross-section studies are prohibited where the same policy is in effect throughout the study area (i. e., separate areas cannot be contrasted when they have the same treatment); and 4) many land use programs do not require reporting of standardized effectiveness measures or targets.

As White (1972: 308) noted, "immense stocks of money and time are expended upon preparation of plans while pitifully small amounts are spent on finding what actually happened after the plans were adopted." Mitchell (1989) suggests the use of hindsight reviews to appraise the implementation of a particular resource management strategy. In addition to benefit-cost analysis and attitude study, he recommends historical for determining policy effectiveness. In a historical assessment, a detailed history of policy creation and implementation is constructed, such that "the situation prior to the conception and implementation of policies and programmes (is) established, and subsequent events (are) described and explained" (Mitchell 1989: 227). The main approach of this type of study is to trace the evolution of the policy from its initial conception through implementation by reviewing historical documents, letters and journals, agency reports, newspaper articles, expert testimony, as well as interviews with people involved with the policy and its operation. At least a few studies have applied the historical approach to the implementation of a resource policy in the water resource management field (Bauer 1980; Décamps et al. 1988; Newson 1992b; Shrubsole 1992; Kleiman and Erickson 1996; Mullens 1995).

The historical assessment method works well with studies that analyze changes over time, because often the influence of unique events and policies can be determined by comparing pre- and post-test conditions. In the case where a new policy is formulated and enacted, the historical assessment method begins with a statement of the administrative and environmental conditions preceding the policy implementation, and then details the events and changes that come as a result of the policy. Mullens (1995) used this method to determine the effectiveness of two conservation policies enacted by the Northwest Power Planning Council from 1984-1993. Shrubsole (1992) reported on over 35 years of the development of the Grand Valley (Ontario) Conservation Authority. By focusing on expenditures and conflicts associated with the development of the authority, he highlighted its pivotal decisions and problems, which allowed him to comment on the overall effectiveness of the authority.

In a special issue of the journal *Landscape and Urban Planning*, several articles gave specific attention to evaluation of greenway policies (Fabos 1995). Among the articles were assessments of greenway programs and management plans (Baschak and Brown 1995; Ryder 1995; Quayle 1995), as well as a critique of a greenway development in upstate New York which employed a participatory democracy framework (Hoover and Shannon 1995). The authors examined the simple and complex forms of cooperative discourse during policy deliberation, and concluded that the greenway planning method relies heavily upon local authority and informal personal communication. Their use of a survey, in addition to the identification of cross-jurisdictional linkages, allowed them to comment on participatory democracy in the greenway planning process.

At least two evaluations of the WRG have been conducted, both mainly concerned with administrative functioning. Bauer (1980) conducted a dialectical study which examined the political framework of the greenway and concluded that it was an administrative failure because early policy makers did not look objectively at social and political conditions along the river and made several political mistakes. Bauer's dialectical model presents Straub's original greenway idea (promoting recreational opportunities along the river) as the event thesis, and the resulting backlash from farmers and other rural protectionists as the antithesis, and then the conciliatory programs implemented by DLCD and the legislature as the event synthesis. To defend his model, Bauer collected and analyzed hundreds of articles, documents, reports, letters, minutes, and interviews from the initial presentation of the greenway plan in 1966 to the early implementation period in 1978. Only by digging deeply into the full progression of events was he able to completely characterize the greenway development event as a dialectical process.

McPherson (1992) conducted a survey of 24 local land use planners and determined that, from their perspective, "the recreational aspect has been most successful, while habitat, riparian area, and other environmental protection aspects need improvement" (p. 65). McPherson recommended an improved organizational structure and a more focused commitment from state leaders. He also suggested that a detailed inventory of state lands be conducted and transferred into a Geographic Information System (GIS). He based his conclusions both on the survey and on his literature review, which relied heavily on Bauer (1980).

Other authors have recommended that the Greenway program be revised to address ecological goals first and foremost, in response to the concern that wildlife habitat and biological diversity are being threatened by population growth pressures in the Willamette valley (Frenkel et al. 1996).

EVALUATION OF LAND USE POLICIES AND LANDSCAPE CHANGE

Perhaps because of their contentious nature, which pits landowners against planners, land use policies have received a great deal of attention from academics (Healy 1976; Mather 1986; Platt 1996). The typical assessment of a land control policy involves political science theory, often analyzing the various roles and decisions of public groups competing in response to local rules (Kaiser et al. 1995), or in a broader sense, evaluating the efficiency and effectiveness of different agencies and their methods (May 1993). Methods similar to the historical assessment are common, particularly since it is difficult to analyze the present problems of a particular policy without having demonstrated the development of those problems through the inception and implementation of the policy. In order to comment on how a policy failed or succeeded, it is essential to trace its failure or success over time (Rossi et al. 1979). A useful addition to this approach is to incorporate statistical information to support the evaluation summary. This method is used by Nelson and Moore (1996) in their assessment of Oregon's land use planning program. The authors outline the development of the planning program since 1973, and then present tabular data relating to four selected study areas from 1980-89. Their statistical evidence elucidates theoretical issues concerning the implementation of UGB restrictions.

One problem with purely theoretical and qualitative implementation evaluations is that they rely heavily on the structural design of the researcher. For that reason, these studies are difficult to replicate and different analysts could construct vastly different conclusions. The use of quantitative data can greatly enhance research evaluations (Mark et al. 2000). For land use control policies, these data are most often tabulations of actual land use changes (Mundie 1982) or other expressions of the landscape-level effects of a policy implementation (Valladares 1993). A complete investigation of the interrelationships between land use controls and landscape change would also require extensive historical research into judicial and planning agency archives in order to gain a clear picture of all the factors behind particular issues and actions.

A recent development in land use planning evaluation is to investigate land cover changes over time, and relate those changes to socio-economic factors or even land control policies (Bockstael 1996). A central assumption with this method is that the existing land cover (i. e., shrub, pine trees, concrete, corn, etc.) is indicative of a location's land use type (i. e., agriculture, urban, forest, rural, etc.) (Turner and Meyer 1994). This method of analysis has become more common since the advent of landscape ecology, which emphasizes the discovery of landscape patterns and processes at various scales (Naveh and Lieberman 1984; Forman and Godron 1986; Turner 1989). Similar to studies which address the causes of land use change at global and regional scales (Turner et al. 1994), local land use change studies relate land cover conversion to a variety of factors, including topography and soils (Iverson 1988; Erickson 1995), urbanization and population growth (Levia 1998; Wear et al. 1999; Kline et al. 2001), road building (Nelson and Hellerstein 1997; Helmer 2000), agricultural economics (Kleiman and Erickson 1996), ownership (Turner et al. 1996), and land use planning (Kline and Alig 1999). The general trend in the past few decades appears to be increased urbanization, suburban sprawl, conversion of agricultural lands to housing, and both afforestation and deforestation as a result of an increasing urban population (Turner and Ruscher 1988; Erickson 1995; Kleiman and Erickson 1996; Turner et al. 1996; Levia 1998; Wear et al. 1999).

The empirical evidence suggests that land use change is a function of population and income growth, depending on the type of land use and other variables such as landowner's characteristics (Alig and Healy 1987; Kline et al. 2000) and ownership patterns (Spies et al. 1994; Turner et al. 1996). The role of land use controls in prodding or preventing landscape change is an important area for further study, but it appears that land use planning efforts are only effective when they are effectively implemented (Patterson 1988). Evaluating Oregon's land use planning program, Kline and Alig (1999) have shown that intensive land use development is confined to within UGBs, but that in rural areas, change occurred frequently on both forests and farms. In other words, land use controls outside of cities did not always protect resource lands from conversion.

SPATIAL METHODS FOR LAND COVER CHANGE ANALYSIS

The development of empirical methods for evaluating the effectiveness of land use controls has been greatly enhanced by the recent development of new spatial methods. Most of the previously referenced studies were performed using county- or census-level summary data. Modern geospatial techniques allow more discrete analyses, with pixel-level differentiation and a wide variety of explanatory variables derived from readily available spatial data sets (Theobald and Hobbs 1998). As a result, spatial methods offer more scientific tools for evaluation of policy implementation; rather than relying solely upon a classic theoretical model or regional tabulations, spatial methods now allow assessment of fine-scale landscape changes in response to variable conditions across the region (Aspinall 1993).

A key component of spatial analysis of land cover change is the application of a GIS. Developed for a wide variety of geographic tasks, these powerful computer-based systems are gaining increasing importance in both landscape ecology (Johnson 1990; Stow 1993) and social science (Rindfuss and Stern 1998). They greatly increase the performance of ecologically based land planning methods (Hendrix et al. 1988; Allen 1994), as well as the assessment of land planning policies (Gross et al. 1987; Aspinall 1993) and projected growth (Bradshaw and Muller 1998). One compelling benefit of a GIS is the rapid ability to shift spatial scales, so that local, regional, and even global analyses can be performed using the same data set. In addition, GIS models are adaptable to most theoretical constructs of land use change; in fact, models of human behavior need to become more spatially explicit to capture the computational power of a GIS (Geoghegan et al. 1998).

The typical approach to using a GIS for land cover change analysis is to construct land cover layers (digital representations of landscape features) for different time slices, and then report the difference between those layers over time. The GIS can quickly tabulate the total area of regions associated with different change vectors, and can also summarize descriptive statistics which link those areas to other landscape variables of interest. As an example, Iverson (1988) compared digital layers of land cover for Illinois from 1820 (digitized from a paper map) and 1980 (derived from aerial photography), and then summarized the changes by a third layer, the statewide soils map (also digitized from paper maps). His analysis not only captured the spatial extent and pattern of land use change over the 160-year time period, but also associated changes with a separate feature of the natural landscape.

Because of the large extent of coverage possible with a GIS, an important element in landscape change analysis is the development of land cover layers. For historical maps, data are often digitized from existing paper maps, or even developed from written reports, such as surveyor records (Dawdy 1989; Russell 1997). Beginning in the 1930's, aerial photography became a standard method of data acquisition. Historic photos, as well as more recent, can be converted into digital land cover layers via photo interpretation and digitizing techniques (Erickson 1995). Since the early 1960's, however, the availability of CORONA, Landsat and other satellite remote sensing platforms has given researchers an indispensable tool for creating land cover layers (Lillesand and Kiefer 2000; Cloud 2001). Satellite images cover large areas, and can be combined to map entire states or even nations (Fuller et al. 1994; Homer et al. 1997; Vogelmann et al. 1998). One advantage of satellite data is that the format of the imagery remains relatively consistent, such that images captured years apart can be handled in similar ways. In fact, since the library of imagery dates back almost 40 years now, spatial patterns of recent landscape change can be revealed relatively quickly (i. e., without extensive interpretation of historical records or aerial photographs) (Mouat et al. 1993). Satellite imagery has been applied extensively to change analysis of forests (Collins and Woodcock 1996; Cohen et al. 1998), urban areas (Haack et al. 1987; Emmanuel 1997), wetlands (Auble 1989; Jensen et al. 1995; Michener and Houhoulis 1997), and entire landscapes (Pax-Lenney et al. 1996; Mouat and Lancaster 1996).

The pixel- and polygon-level information associated with remote sensing and GIS land cover layers presents distinct advantages over coarse-scale land cover change summaries, because discrete events at a multitude of sample points can be analyzed for statistical relationships (Baker 1989). Using econometric principles, logistic regression techniques have been employed to indicate probabilities associated with land use changes. For example, Turner et al. (1996) analyzed differences in public and private ownership of forest lands in parts of North Carolina and Washington. They found that both physical (slope, elevation) and cultural (distance to roads and markets, population density) features had significant influence on forest cover change dynamics. Wear and Bolstad (1998) examined similar explanatory variables in four study areas in the southern Appalachian Mountains. They reported comparable results and used the relationships to construct forecast models to predict landscape conversion throughout the region. In the same vein, Kline et al. (2001) examined multiple variables (including forest commodity values, farm commodity values, income, ownership, elevation, and proximity to roads) for over 2000 data points on private forest and agricultural land to calculate logistic regression models which predict the probability of urbanization. Their models allow pixel-by-pixel predictions of urbanization potential across a regional landscape. Such efforts are important for planners and ecologists faced with expanding urban populations and undesirable landscape changes (Briassoulis 2001).

SPATIAL METHODS FOR RIPARIAN CHANGE ASSESSMENT

Many studies have demonstrated a strong relationship between landscape characteristics and stream quality, especially with regard to the presence or absence of a well-developed riparian zone (Schlosser and Karr 1981; Lowrance et al. 1985; Décamps et al. 1988; Roth et al. 1996). For this and many other reasons, there has been an increasing amount of attention on mapping riparian structure and land cover change along rivers. The techniques employed in riparian mapping studies range from field sampling to satellite remote sensing, and in recent years almost all this type of work involves a GIS (Muller 1997).

A GIS is well suited to analysis of a river system because it can be easily adapted to integrate a variety of physical and artificial phenomena over wide scales of space and time (Johnson 1990; Kaden 1993). In riverine management, a GIS offers powerful support for decision makers, since "the parameters of interest are often distributed spatially across the river basin and temporally through a season, a year, or a critical period" (Goulter and Forrest 1987: 82). In addition, a GIS is readily incorporated within existing river models and regulation strategies (Smith et al. 1990). Four relevant areas which have recently benefited from the application of GIS are riparian vegetation classification (Delong and Brusven 1991; Hewitt 1990), greenway development (Smith and Hellmund 1993), river change studies (Décamps et al. 1988; Kienast 1993), and ecosystem management (Haines-Young et al. 1993; Kovar and Nachtnebel 1993; Slocombe 1993). In riparian land cover change mapping, a key concern becomes the spatial resolution of mapping detail, which is essentially a function of the type of spatial data available.

For many aquatic ecologists, the preferred method of collecting spatial information for riparian mapping is directly from field studies. The high level of spatial resolution and high degree of species classification greatly benefits the power of associations between fine-level landscape features and stream responses (Delong and Brusven 1991). This is the approach taken by Hupp (1992), who collected detailed information on the relationships between geomorphology and the vegetation response to river channelization in western Tennessee. The work is very time-intensive, however; his study required six years of field collection to analyze 150 point surveys on 15 rivers. Field methods work best on localized studies, such as Tabacchi et al. (1990), who mapped 31 sites along the River Adour in southwest France to demonstrate floristic connectivity along the length of the river. While field studies allow collection of detailed information, they can be prohibitively time-consuming and costly.

The use of aerial photographs can increase the spatial extent of a riparian mapping study, but it comes at the expense of classification detail. One major advantage of using aerial photographs is the availability of historic photos, which became available in the 1930's (Russell 1997; Williams and Lyon 1997; Brewster et al. 1999). For example, Hoar and Erwin (1985) analyzed air photos from 1938, 1956, 1974, and 1982 to assess riparian land cover change along a 136-mile stretch of the Missouri River in eastern Montana. They found that the amount of agricultural land in the floodplain increased from 24% to 55%, at the expense of herbaceous and shrub-scrub cover, and concluded that there is just cause for concern over the conversion of riparian habitat due to agricultural expansion. In contrast, Kleiman and Erickson (1996), using aerial photographs and a digital land cover layer, discovered an increasing trend in riparian forest along the River Raisin in southeast Michigan. They concluded that growth in the suburban population had displaced farms, and that shifts in agricultural practices had promoted tree growth along the river.

Many researchers have supplemented the use of aerial photographs with fine-scale historic maps (Squires 1992) and surveyor notes to map streamside vegetation and other riparian features. While most of these studies are designed to assess the geomorphic transition of rivers, they also offer potential for detailing riparian land cover (Downward et al. 1994; Gurnell 1997; Mossa and McLean 1997).

Satellite-based remote sensing data have been applied to riparian land cover mapping with some success. An advantage of Landsat and other satellite imagery is that large areas can be rapidly mapped, providing information not only on the river floodplain, but also the surrounding landscape (Hewitt 1990). Since Landsat imagery is available from 1972 on, riparian land cover change detection studies are also possible (Lee and Marsh 1995). Used in conjunction with GIS methods, satellite imagery has also been used to help delineate riparian buffer zones (Narumalani et al. 1997) and select potential sites for riparian restoration (Russell et al. 1997).

An important concern with mapping riparian land cover is the selection of spatial resolution. High-resolution sensors allow greater detail and classification accuracy, but increase cost and processing time (Rowlinson et al. 1999; Congalton et al. 2000). Advanced methodologies employing high-resolution (i. e., < 1m pixel size) airborne multi-spectral videography show great promise in capturing riparian details on small streams, but the processing costs can be prohibitive, and therefore these methods have only been applied in very small study areas (Neale 1997; Wright et al. 2000). For larger study areas, such as large river floodplains, satellite remote sensing data appear to be the best available information for riparian cover mapping, especially when used in conjunction with available GIS data layers (Muller 1997).

One important riparian mapping study with significance to the WRG is Wickramaratne (1983; see also Frenkel et al. 1983; Frenkel et al. 1984). In this study, the author used aerial photography from 1972 and 1981 to map land cover change within the WRG in Benton and Linn counties. He found that there was a net loss of riparian vegetation during that time period due to conversion of forest to agriculture and sand and gravel operations. Within a 5,185 ha study area in Benton and Linn

Counties, 294 ha of the aggregated riparian vegetation was lost to agriculture and development, about 78% to agriculture and 22% to development, mostly sand and gravel operations (Wickramaratne 1983). This study suggests that land conversion occurred in spite of the presence of land use controls along the Willamette River.

OVERVIEW

The general objective of my study is to characterize historical landscape change along the Willamette River. The results of this work will help researchers and policy makers track historical changes in the river and its floodplain, develop a baseline of modern-day land cover conditions, and identify potential sites for floodplain restoration. Once the historical and modern conditions of the floodplain have been characterized, commentary on the nature of change along the river and the relationship of those changes to the land use planning process can be elucidated. I plan to do this in a later study which will evaluate the implementation of state land use planning Goal #15.

The primary justification for this project is to develop new methodologies for mapping floodplain change. While a societal purpose is not required of all scientific pursuits, one possible contribution of this research is to assist in restoring the natural integrity of the Willamette River floodplain, which would benefet society in a wide variety of ways (Bayley 1995). The remote sensing and GIS methods described in the chapters below outline a spatial approach which can assist the restoration effort.

The general objective will be achieved through three research tasks:

Objective 1: To develop GIS methodologies for temporal analysis of the Willamette River floodplain which can be used to assist in identifying potential sites for riparian restoration.

This objective is to investigate the methods for characterizing the river floodplain at different time periods using different data sources. Using GIS, the spatial information from those time periods can be compared to analyze the changes over time. An end result of this analysis is data which can be used to help prioritize floodplain locations for potential ecologic restoration. This research is presented in Chapter 2, "GIS methodology for characterizing historical conditions of the Willamette River floodplain, Oregon."

Objective 2: To characterize the present condition of the lands inside and adjacent to the Willamette River Greenway.

This objective is to create a recent land cover map which can be used to isolate general land cover types along the WRG. A current map helps stratify the change detection methods of Objective 2. A secondary objective is to report methods for determining land cover types in an agricultural setting using the Kauth-Thomas (1976) Tasseled Cap transformation for Landsat imagery. This work is reported in Chapter 3 of this thesis, "Land cover mapping in an agricultural setting using multi-seasonal Thematic Mapper data."

Objective 3: To determine the direction and magnitude of landscape change along the Willamette River Greenway from 1976-1995.

The purpose of this objective is to characterize the land use and land cover change within and adjacent to the WRG during the time period that Goal #15 has been in effect. Using the land cover map created in Objective 2, satellite remote sensing data from 1976, 1984, and 1995 are used to create a land cover change map. A secondary objective is to assess the benefits of using satellite remote sensing as compared to aerial photography methods such as in Wickramaratne (1983). This work is reported in Chapter 4, "Land cover change detection along the Willamette River Greenway, Oregon."

A summary chapter concludes the thesis by presenting significant findings and contributions, as well as providing commentary on the research objectives and their relationship to the field of resource geography. One portion of the summary chapter describes how these three technical research projects will fuel future research to evaluate the effectiveness of the WRG in restricting landscape change along the river. In a sense, these technical papers, each of which contributes some direct ecological and resource management value on its own, lay the groundwork for a research project to evaluate land use policy goal (Geoghegan et al. 1998).

REFERENCES

Abbott, Carl, Deborah Howe, and Sy Adler. 1994. *Planning the Oregon way: a twenty-year evaluation*. Corvallis, Oregon: Oregon State University Press.

Alig, Ralph J. and Robert G. Healy. 1987. Urban and built-up land area changes in the United States: an empirical investigation of determinants. *Land Economics* 63(3):215-226.

Allan, J. David and Alexander S. Flecker. 1993. Biodiversity conservation in running waters. *BioScience* 43(1):32-43.

Allen, Craig D. 1994. Ecological perspective: linking ecology, GIS, and remote sensing to ecosystem management. In *Remote sensing and GIS in ecosystem managment*, edited by Sample, V. Alaric. (Covelo, Calif.: Island Press).

Aspinall, R. 1993. Use of geographic information systems for interpreting land-use policy and modelling effects of land-use change. In *Landscape Ecology and Geographic Information Systems*, edited by Haines-Young, Roy H., David R. Green, and Steven Cousins. (London: Taylor & Francis).

Auble, Gregor T. 1989. Modeling wetland and riparian vegetation change. Paper presented at Wetlands and River Corridor Management, at Berne, New York.

Baker, William L. 1989. A review of models of landscape change. *Landscape Ecology* 2(2):111-133.

Baschak, Lawrence A. and Robert D. Brown. 1995. An ecological framework for the planning, design and management of urban river greenways. *Landscape and Urban Planning* 33:211-225.

Bauer, Webb S. 1980. A Case Analysis of Oregon's Willamette River Greenway Program. Oregon State University Department of Geography, Corvallis, Oregon.

Baumann, Duane D. and Daniel Dworkin. 1978. *Water Resources for Our Cities., Resource Papers for College Geography*. Washington: Association of American Geographers.

Bayley, Peter B. 1995. Understanding large river-floodplain ecosystems. *BioScience* 45(3):153-158.

Benner, P.A. and Sedell, J.R., 1997. Upper Willamette River landscape: a historic perspective. In: A. Laenen and D.A. Dunnette (Editors), River quality: dynamics and restoration. Lewis Publishers, Boca Raton, pp. 23-47.

Binford, Michael W. and Michael J. Buchenau. 1993. Riparian greenways and water resources. In *Ecology of Greenways: Design and Function of Linear Conservation Areas*, edited by Smith, Daniel S and Paul Cawood Hellmund. (Minneapolis: University of Minnesota Press).

Bockstael, Nancy E. 1996. Modeling economics and ecology: the importance of a spatial perspective. *American Journal of Agricultural Economics* 78:1168-1180.

Bolling, David M. 1994. *How to Save a River: A Handbook for Citizen Action*. Covelo, Calif.: Island Press.

Boon, P. J. 1992. Essential elements in the case for river conservation. In *River conservation and management*, edited by Boon, P. J., P. Calow, and G. E. Petts. (New York: John Wiley & Sons).

Bradshaw, Ted K. and Brian Muller. 1998. Impacts of rapid urban growth on farmland conversion: application of new regional land use policy models and geographic information systems. *Rural Sociology* 63(1):1-25.

Brewster, C. C., J. C. Allen, and D. D. Kopp. 1999. IPM from space: Using satellite imagery to construct regional crop maps for studying crop-insect interaction. *American Entomologist* 45:105-117.

Briassoulis, Helen. 2001. Policy-oriented integrated analysis of land-use change: an analysis of data needs. *Environmental Management* 27(1):1-11.

Bunting, Robert. 1997. *The Pacific raincoast: environment and culture in an American Eden, 1778-1900*. Lawrence: University Press of Kansas.

[CAETEP] Committee on the Applications of Ecological Theory to Environmental Problems, National Research Council. 1986. *Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies*. Washington, D. C.: National Academy Press.

Chauvet, E. and Henri Décamps. 1989. Lateral interactions in a fluvial landscape: The River Garonne, France. *Journal of the North American Benthological Society* 8(1):9-17.

Chorley, Richard J. 1969. *Water, earth and man: a synthesis of hydrology, geomorphology and socio-economic geogrpahy*. London: Methuen.

Cloud, John. 2001. Imaging the world in a barrel: CORONA and the clandestine convergence of the earth sciences. *Social Studies of Science* 31(2): 231-251.

Cohen, Warren B., Maria Fiorella, John Gray, Eileen Helmer, and Karen Anderson. 1998. An efficient and accurate method for mapping forest clearcuts in the Pacific Northwest using Landsat imagery. *Photogrammetric Engineering & Remote Sensing* 64:293-300.

Collins, John B. and Curtis E. Woodcock. 1996. An assessment of several linear change detection techniques for mapping forest mortality using multitemporal Landsat TM data. *Remote Sensing of Environment* 56:66-77.

Congalton, Russell G., Kevin Birch, Rick Jones, Jay Powell, and James Schriever. 2000. Evaluating remotely sensed techniques for mapping riparian vegetation. Paper presented at Second International Conference on Geospatial Information in Agriculture and Forestry.

Corning, Howard McKinley. 1973. *Willamette landings: ghost towns of the river.* Portland, Oregon: Oregon Historical Society.

Cronon, William. 1996. *Uncommon Ground.* New York: W. W. Norton & Co.

Dawdy, David R. 1989. Feasibility of mapping riparian forests under natural conditions in California. Paper presented at Protection, Management, and Restoration for the 1990's: Proceedings of the California Riparian Systems Conference, at Berkeley, California.

Décamps, Henri, Madeleine Fortune, Francois Gazelle, and Guy Pautou. 1988. Historical influence of man on the riparian dynamics of a fluvial landscape. *Landscape Ecology* 1(3):163-73.

Delong, Michael D. and Merlyn A. Brusven. 1991. Classification and spatial mapping of riparian habitat with applications toward management of streams impacted by nonpoint source pollution. *Environmental Management* 15(4):565-571.

Doppelt, Robert. 1993. The vital role of the scientific community in new river conservation strategies. *Journal of the North American Benthological Society* 12(2):189-93.

Downward, S. R., A. M. Gurnell, and A. Brookes. 1994. A methodology for quantifying river channel planform change using GIS. Paper presented at Variability in stream erosion and sediment transport.

Emmanuel, R. 1997. Urban vegetational change as an indicator of demographic trends in cities: the case of Detroit. *Environment and Planning B: Planning and Design* 24:415-426.

Erickson, Donna L. 1995. Rural land use and land cover change: implications for local planning in the River Raisin watershed. *Land Use Policy* 12(3):223-236.

Fabos, Julius Gy. 1995. Introduction and overview: the greenway movement, uses and potentials of greenways. *Landscape and Urban Planning* 33:1-13.

Fabos, Julius Gy. and Jack Ahern. 1996. *Greenways: the beginning of an international movement.* New York: Elsevier.

[FEMAT] Forest Ecosystem Management Assessment Team. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. 1993. Washington, D. C., USDA Forest Service.

Flink, Charles A. 1993. The American greenway movement. *Canadian Water Resources Journal* 18(3):485-492.

Forman, Richard T. T. and Michel Godron. 1986. *Landscape Ecology*. New York: John Wiley & Sons.

Frenkel, Robert E., Stanley V. Gregory, and James R. Sedell. The Willamette River: An ecosystem in need of a new vision. 1996.

Frenkel, Robert E., Eric F. Heinitz, and S. Nimal Wickramaratne. Vegetation changes in the Willamette River Greenway in Benton and Linn counties: 1972-1981. 1983. Corvallis, Oregon, Water Resources Research Institute, Oregon State University.

Frenkel, Robert E., S. Nimal Wickramaratne, and Eric F. Heinitz. 1984. Vegetation and land cover change in the Willamette River Greenway in Benton and Linn Counties, Oregon: 1972-1981. *Association of Pacific Coast Geographers Yearbook* 46:63-77.

Fuller, R. M., G. B. Groom, and A. R. Jones. 1994. The land cover map of Great Britain: an automated classification of Landsat Thematic Mapper data. *Photogrammetric Engineering & Remote Sensing* 60(5):553-562.

Furuseth, Owen J. and Robert E. Altman. 1991. Who's on the greenway: socioeconomic, demographic, and locational characteristics of greenway users. *Environmental Management* 15(3):329-336.

Gardiner, John L. Willamette River floodplain restoration study: section 905(b) reconnaissance report. 1999. Portland, Oregon, Philip Williams & Associates.

Geoghegan, Jacqueline, Lowell Jr. Pritchard, Yelena Ogneva-Himmelberger, Rinku Roy Chowdhury, Steven Sanderson, and B. L. II Turner. 1998. "Socializing the pixel" and "pixelizing the social" in land-use and land-cover change. In *People and pixels: linking remote sensing and social science*, edited by Liverman, Diana, Emilio F. Moran, Ronald R. Rindfuss, and Paul C. Stern. (Washington, D. C.: National Academy Press).

Giller, Paul S. and Björn Malmqvist. 1998. *The Biology of Streams and Rivers*. Oxford: Oxford University Press.

Gleeson, George W. The Return of a River: The Willamette River, Oregon. 1972. Corvallis, Ore, Water Resources Research Institute, Oregon State University.

Good, James W. 1992. Ocean Shore Protection Policy and Practices in Oregon: An Evaluation of Implementation Success. Oregon State University, Corvallis, Oregon.

Gosselink, James G., Gary P. Shaffer, Lyndon C. Lee, David M. Burdick, Daniel L. Childers, Nancy C. Leibowitz, Susan C. Hamilton, Roel Boumans, Douglas Cushman, Sherri Fields, Marguerite Koch, and Jenneke M. Visser. 1990. Landscape conservation in a forested wetland watershed: Can we manage cumulative impacts? *BioScience* 40(8):588-600.

Goudie, Andrew. 1994. *The Human Impact on the Natural Environment.* 4th ed. Cambridge, Mass.: The MIT Press.

Goulter, I. C. and D. Forrest. 1987. Use of geographic information systems (GIS) in river basin management. *Water Science and Technology* 19(9):81-86.

Graf, William L. 2001. Damage control: restoring the physical integrity of America's rivers. *Annals of the Association of American Geographers* 91(1):1-27.

Gregory, Stanley V. Ecological, demographic, and economic evaluation of opportunities and constraints for riparian restoration. 1999.

Gregory, Stanley V., Frederick J. Swanson, W. Arthur McKee, and Kenneth W. Cummins. 1991. An ecosystem perspective of riparian zones. *BioScience* 41(8):540-51.

Gross, Meir, Julius Gy. Fabos, Charles L. Tracy, and Michael Waltuch. 1987. Computer-assisted land use planning: a study of the Connecticut Greenway. *Land Use Policy* 4(1):31-41.

Grove, Noel. 1990. Greenways: paths to the future. *National Geographic* 177(6):77-99.

Guelke, Leonard. 1971. Problems of scientific explanation in geography. *Canadian Geographer* 15(1):38-53.

Gurnell, A. M. 1997. Channel change on the River Dee meanders, 1946-1992, from the analysis of air photographs. *Regulated Rivers: Research & Management* 13:13-26.

Gustafson, Greg C., Thomas L. Daniels, and Rosalyn P. Shirack. 1982. The Oregon land use act. *Journal of the American Planning Association* 48(3):365-373.

Gutowsky, Sharon and Julia A. Jones. 2000. Riparian cover changes along the upper Willamette River, 1939 to 1996. Paper presented at International Conference on Riparian Ecology and Management in Multi-land use Watersheds.

Haack, Barry, Nevin Bryant, and Steven Adams. 1987. An assessment of Landsat MSS and TM data for urban and near-urban land-cover digital classification. *Remote Sensing of Environment* 21:201-213.

Haines-Young, Roy H., David R. Green, and Steven Cousins. 1993. *Landscape Ecology and Geographic Information Systems.* London: Taylor & Francis.

Harrald, John R., Kirk R. Karwan, Joseph V. Leotta, and William A. Wallace. 1979. Assessing the effectiveness of a marine environmental protection program. In *Program evaluation in the public sector*, edited by Hyde, Albert C. and Jay M. Shafritz. (New York: Praeger).

Healy, Robert G. 1976. *Land use and the states*. Baltimore: Resources for the Future.

Helmer, Eileen H. 2000. The landscape ecology of tropical secondary forest in montane Costa Rica. *Ecosystems* 3:98-114.

Hendrix, William G., Julius Gy. Fabos, and Joan E. Price. 1988. An ecological approach to landscape planning using geographic information system technology. *Landscape and Urban Planning* 15(3/4):211-25.

Hewitt, Mason J. III. 1990. Synoptic inventory of riparian ecosystems: The utility of Landsat Thematic Mapper data. *Forest Ecology and Management* 33/34:605-620.

Hoar, Alexander R. and Michael J. Erwin. 1985. Relationships between the expansion of agriculture and the reduction of natural riparian habitat in the Missouri River floodplain of northeast Montana, 1938-1982 . Paper presented at Proceedings of the First North American Symposium on Riparian Ecosystems and Their Management.

Homer, Collin G., R. Douglas Ramsey, Thomas C. Jr. Edwards, and Allan Falconer. 1997. Landscape cover-type modeling using a multi-scene Thematic Mapper mosaic. *Photogrammetric Engineering & Remote Sensing* 63(1):59-67.

Hoover, Anne P. and Margaret A. Shannon. 1995. Building greenway policies within a participatory democracy framework. *Landscape and Urban Planning* 33:433-459.

Hupp, Cliff R. 1992. Riparian vegetation recovery pattterns following stream channelization: A geomorphic perspective. *Ecology* 73(4):1209-26.

Iverson, Louis R. 1988. Land-use changes in Illinois, USA: the influence of landscape attributes on current and historic land use. *Landscape Ecology* 2(1):45-61.

Jensen, J. Granville. 1964. Paper presented at Spatial Organization of Land Uses: The Willamette Valley, at Corvallis, Oregon.

Jensen, John R., Ken Rutchey, Marguerite S. Koch , and Sunil Narumalani. 1995. Inland wetland change detection in the Everglades water conservation Area 2A using a time series of normalized remotely sensed data. *Photogrammetric Engineering & Remote Sensing* 61(2):199-209.

Johannessen, Carl L., William A. Davenport, Artimus Millet, and Steven McWilliams. 1970. The vegetation of the Willamette Valley. *Annals of the Association of American Geographers* 61:286-302.

Johnson, Lucinda B. 1990. Analyzing spatial and temporal phenomena using geographical information systems: A review of ecological applications. *Landscape Ecology* 4(1):31-43.

Johnston, R J. 1993. Meet the challenge: make the change. In *The Challenge for Geography: A Changing World: A Changing Discipline*, edited by Johnston, R J. (Oxford: Blackwell).

Kaden, Stefan O. 1993. GIS in water-related environmental planning and management: problems and solutions. Paper presented at HydroGIS 93: Application of Geographical Information Systems to Hydrology and Water Resources, at Wallingford,UK.

Kaiser, Edward J., David R. Godschalk, and F. Stuart Chapin Jr. 1995. *Urban Land Use Planning*. Urbana: University of Illinois Press.

Karr, James R. and Isaac J. Schlosser. 1978. Water resources and the land-water interface. *Science* 201(21 July):229-34.

Kauth, R. J. and G. S. Thomas. 1976. The Tasseled Cap- a graphic description of the spectra-temporal development of agricultural crops as seen by Landsat. Paper presented at Proceedings of the Symposium on Machine Processing of Remotely Sensed Data.

Kienast, Felix. 1993. Analysis of historic landscape patterns with a geographical information system- a methodological outline. *Landscape Ecology* 8(2):103-18.

Kleiman, R. E. and D. L. Erickson. 1996. Landscape change in an agricultural watershed: the effect of parcelization on riparian forest cover. *Environment and Planning B: Planning and Design* 23:25-36.

Kline, Jeffrey D. and Ralph J. Alig. 1999. Does land use planning slow the conversion of forest and farm lands? *Growth and Change* 30:3-22.

Kline, Jeffrey D., Ralph J. Alig, and Rebecca L. Johnson. 2000. Forest owner incentives to protect riparian habitat. *Ecological Economics* 33:29-43.

Kline, Jeffrey D., Alissa Moses, and Ralph J. Alig. 2001. Integrating urbanization into landscape-level ecological assessments. *Ecosystems* 4:3-18.

Kovar, K. and H. P. Nachtnebel. HydroGIS 1993: Application of Geographic Information Systems in Hydrology and Water Resource Planning. 1993. Wallingford, UK, International Association of Hydrological Sciences.

Labaree, Jonathan. 1992. *How Greenways Work: A Handbook on Ecology*. Ipswich, Mass.: National Park Service and the Atlantic Center for the Environment.

LaFayette, Russell and Leonard F. DeBano. 1990. Watershed condition and riparian health: Linkages. In *Watershed Planning and Analysis in Action*, edited by Riggins, Robert E., E. Bruce Jones, Ranvir Singh, and Paul A. Rechard. (New York: American Society of Civil Engineers).

Lee, Christopher T. and Stuart E. Marsh. 1995. The use of archival Landsat MSS and ancillary data in a GIS environment to map historical change in an urban riparian habitat. *Photogrammetric Engineering & Remote Sensing* 61(8):999-1008.

Leland, David, Steven Anderson, and Donald J. Jr. Sterling. 1997. The Willamette- a river in peril. *Journal of the American Water Works Association* 89(11):73-83.

Leopold, Aldo. 1966. *A Sand County Almanac.* New York: Ballantine Books.

Leopold, Luna B. 1997. *Water, Rivers and Creeks.* Sausalito, Calif.: University Science Books.

Levia, D. F. 1998. Farmland conversion and residential development in north central Massachusetts. *Land Degradation & Development* 9:123-130.

Likens, Gene E. and Herbert F. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. *BioScience* 24(8):447-56.

Lillesand, Thomas M., and Ralph W. Kiefer. 2000. *Remote Sensing and Image Interpretation.* New York: John Wiley & Sons.

Lindsey, Greg, Maltie Maraj, and SonCheong Kuan. 2001. Access, equity, and urban greenways: an exploratory investigation. *The Professional Geographer* 53(3):332-346.

Little, Charles E. 1974. *The new Oregon trail: an account of the development and passage of state land-use legislation in Oregon.* Washington, D. C., The Conservation Foundation.

Little, Charles E. 1990. *Greenways for America.* Baltimore: The Johns Hopkins University Press.

Lowrance, Richard, Ralph Leonard, and Joseph Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. *Journal of Soil and Water Conservation* 40(1):87-91.

Lowrance, Richard, Robert Todd, Joseph Jr. Fail, Ole Jr. Hendrickson, Ralph Leonard, and Loris Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. *BioScience* 34(6):374-77.

Malanson, George P. 1993. *Riparian Landscapes.* New York: Cambridge University Press.

Marcus, Melvin G. 1979. Coming full circle: physical geography in the twentieth century. *Annals of the Association of American Geographers* 69(4):521-532.

Mark, Melvin M., Gary T. Henry, and George Julnes. 2000. *Evaluation: an integrated framework for understanding, guiding, and improving public and nonprofit policies and programs.* San Francisco: Jossey-Bass.

Marsh, George Perkins. 1864. *Man and nature: or, physical geography as modified by human action.* New York: Charles Scribner.

Mather, A. S. 1986. *Land use.* Essex: Longman Group U. K. Ltd.

Mather, John R. 1984. *Water Resources: Distribution, Use, and Management* . New York: John Wiley & Sons.

May, Peter J. 1993. Mandate design and implementation: enhancing implementation efforts and shaping regulatory styles. *Journal of Policy Analysis and Management* 12(4):634-663.

Mazmanian, Daniel A. and Paul A. Sabatier. 1981. *Effective Policy Implementation.* Lexington, Mass.: Lexington Books.

McHarg, Ian. 1971. *Design with Nature.* Garden City, N. Y.: Doubleday & Co., Inc.

McPherson, John Lawrence. 1992. The Willamette River Greenway: A Program Analysis. University of Oregon School of Urban Planning, Eugene, Oregon.

Michener, William K. and Paula F. Houhoulis. 1997. Detection of vegetation changes associated with extensive flooding in a forested ecosystem. *Photogrammetric Engineering & Remote Sensing* 63(12):1363-1374.

Miniszewski, Gary. 1979. *Background Information for the Benton County Comprehensive Plan: Willamette River Greenway.* Corvallis, Oregon: Benton County Planning Commission.

Miniszewski, Gary and Marguerite Nabeta. 1993. Willamette river greenway program renewal white paper.

Minshall, G Wayne. 1988. Stream ecosystem theory: A global perspective. *Journal of the North American Benthological Society* 7(4):263-88.

Mitchell, Bruce. 1989. *Geography and resource analysis.* New York: John Wiley & Sons, Inc.

Mossa, J. and M. McLean. 1997. Channel planform and land cover changes on a mined river floodplain, Amite River, Louisiana, U. S. A. *Applied Geography* 17(1):43-54.

Mouat, David A. and Judith Lancaster. 1996. Use of remote sensing and GIS to identify vegetation change in the Upper San Pedro River watershed, Arizona. *Geocarto International* 11(2):55-67.

Mouat, David A., Glenda G. Mahin, and Judith Lancaster. 1993. Remote sensing techniques in the analysis of change detection. *Geocarto International* 2:39-50.

Muckleston, Keith W. 1986. The changing uses of the Willamette River. *Beitrage zur Hydrologie* 6(Kirchzarten):41-57.

Muckleston, Keith W. 1990. Integrated water management in the United States. In *Integrated Water Management: International Experiences and Perspectives,* edited by Bruce Mitchell. (London: Belhaven Press).

Mullens, Jo Beth. 1995. Implementation of Regional Plans in the Pacific Northwest: an Analysis of the Northwest Power Planning Council's Water Budget and Model Conservation Standards 1984-1993. Oregon State University Department of Geography, Corvallis, Oregon.

Muller, Etienne. 1997. Mapping riparian vegetation along rivers: old concepts and new methods. *Aquatic Botany* 58:411-437.

Munch, Ernest R. 1984. River Forum: a sore thumb on the Willamette. *Landmark* 1(2):24-25.

Mundie, R. M. 1982. Evaluating the effectiveness of local government farmland protection programs. *GeoJournal* 6(6):513-517.

Nabeta, Marguerite and Jim Payne. Background information for Willamette River Greenway Program work session, November 8, 1991. 1991.

Nagel, Stuart S. 1990. *Policy Theory and Policy Evaluation.* New York: Greenwood Press.

Naiman, Robert J., Henri Décamps, and Michael Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3(2):209-12.

Narumalani, Sunil, Yingchun Zhou, and John R. Jensen. 1997. Application of remote sensing and geographic information systems to the delineation and analysis of riparian buffer zones. *Aquatic Botany* 58:393-409.

[NRC-CRAE] National Research Council Committee on Restoration of Aquatic Ecosystems- Science, Technology and Public Policy. 1992. *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy.* Washington, D. C.: National Academy Press.

Naveh, Zev and Arthur S. Lieberman. 1984. *Landscape Ecology: Theory and Applications.* New York: Springer-Verlag.

Neale, Christopher M. U. 1997. Classification and mapping of riparian systems using airborne multispectral videography. *Restoration Ecology* 5(4S):103-112.

Nelson, Arthur C. and Terry Moore. 1996. Assessing growth management policy implementation: case study of the United States' leading growth management state. *Land Use Policy* 13(4):241-259.

Nelson, Gerald C. and Daniel Hellerstein. 1997. Do roads cause deforestation? using satellite images in econometric analysis of land use. *American Journal of Agricultural Economics* 79:80-88.

Newson, Malcolm. 1992a. Land, Water, and Development: Sustainable Management of River Basin Systems, 2nd ed. London: Routledge.

Newson, M. D. 1992b. River conservation and catchment management: a UK perspective. In *River conservation and management,* edited by Boon, P. J., P. Calow, and G. E. Petts. (New York: John Wiley & Sons).

[NPS] National Park Service Rivers, Trails and Conservation Assistance Program. 1995. *Economic Impacts of Protecting Rivers, Trails, and Greenway Corridors: A Resource Book.* Washington, D. C.: National Park Service.

[ODOT] Oregon Department of Transportation. Preliminary Willamette River Greenway Plan. 1974. San Francisco, Royston, Hanamoto, Beck & Abey.

Odum, Eugene P. 1978. Ecological importance of the riparian zone. Paper presented at Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems, at Washington, DC.

[OLCDC] Oregon Land Conservation and Development Commission. Oregon's statewide planning goals. 1990. Salem, OLCDC.

[OSPRB] Oregon State Parks and Recreation Branch, Department of Transportation. A Proposal for the Willamette River Greenway. 1976. Salem, Oregon, Oregon State Parks and Recreation Branch, Department of Transportation.

[OSPRD] Oregon State Parks and Recreation Department. Protecting the Best of Oregon, 2010 Plan Phase I, 1993-1999. 1992. Salem, Oregon State Parks and Recreation Department.

Palmer, Tim. 1986. *Endangered Rivers and the Conservation Movement*. Berkeley: University of California Press.

Patterson, T. William. 1988. *Land use planning: techniques of implementation*. Malabar, Florida: Robert E. Krieger Publishing Co.

Pattison, William D. 1964. The four traditions of geography. *Journal of Geography* 63:211-216.

Pax-Lenney, M., C. E. Woodcock, J. B. Collins, and H. Hamdi. 1996. The status of agricultural lands in Egypt: The use of multitemporal NDVI features derived from Landsat TM. *Remote Sensing of Environment* 56:8-20.

Pease, James R. 1982. Commercial farmland preservation in Oregon. *GeoJournal* 6(6):547-553.

Peterjohn, William T. and David L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. *Ecology* 65(5):1466-75.

Petts, G. E., H. Moller, and L. Roux. 1989. *Historical Change of Large Alluvial Rivers: Western Europe*. New York: John Wiley & Sons.

Petts, Geoffrey. 1989. Historical analysis of fluvial hydrosystems. In *Historical Change of Large Alluvial Rivers: Western Europe*, edited by Petts, Geoffrey E., H. Mueller, and A. L. Roux. (New York: John Wiley & Sons).

Platt, John R. 1964. Strong inference. *Science* 146(16 October):347-353.

Platt, Rutherford H. 1992. Geographers and water policy. Paper presented at AWRA National Forum on Water Management Policy.

Platt, Rutherford H. 1996. *Land Use and Society: Geography, Law, and Public Policy* . Washington, D. C.: Island Press.

Pressman, Jeffrey L. and Aaron Wildavsky. 1974. *Implementation*. Berkeley: The University of California Press.

Quayle, Moura. 1995. Urban greenways and public ways: realizing public ideas in a fragmented world. *Landscape and Urban Planning* 33:461-475.

Raad, Maureen F. 1999. Flood Damage Reduction and Riparian Floodplain Forest Restoration: Selecting Focal Areas and Setting Restoration Goals on Oregon's Willamette River. Eugene, OR; Masters Project, Department of Landscape Architecture, University of Oregon.

Rapp, Valerie. 1997. *What the River Reveals*. Seattle: The Mountaineers.

Rindfuss, Ronald R. and Paul C. Stern. 1998. Linking remote sensing and social science: the need and the challenges. In *People and pixels: linking remote sensing and social science*, edited by Liverman, Diana, Emilio F. Moran, Ronald R. Rindfuss, and Paul C. Stern. (Washington, D. C.: National Academy Press).

River Network. Draft proposal for a Willamette River floodway project. 1995.

Robbins, William G. 1974. *Land: its use and abuse in Oregon, 1848-1910*. Corvallis, Oregon, Oregon State University.

Robbins, William G. 1997. *Landscapes of Promise: The Oregon Story 1800-1940*. Seattle: University of Washington Press.

Rohse, Mitch. 1987. *Land-Use Planning in Oregon: A No-Nonsense Handbook in Plain English*. Corvallis, Oregon: Oregon State University Press.

Rossi, Peter H., Howard E. Freeman, and Sonia R. Wright. 1979. *Evaluation: a systematic approach*. Beverly Hills: Sage Publications.

Roth, Nancy E., J. David Allan, and Donna L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology* 11(3):141-156.

Rowlinson, Lisa C., Mark Summerton, and Fethi Ahmed. 1999. Comparison of remote sensing data sources and techniques for identifying and classifying alien invasive vegetation in riparian zones. *Water SA* 25(4):497-500.

Russell, Emily W. B. 1997. *People and Land through Time*. New Haven: Yale University Press.

Russell, Gordon D., Charles P. Hawkins, and Michael P. O'Neill. 1997. The role of GIS in selecting sites for riparian restoration based on hydrology and land use. *Restoration Ecology* 5(4S):56-68.

Ryder, Barbara A. 1995. Greenway planning and growth management: partners in conservation? *Landscape and Urban Planning* 33:417-432.

Sauer, Carl Ortwin. 1956. The education of a geographer. *Annals of the Association of American Geographers* 46:287-299.

Schlosser, Isaac J. and James R. Karr. 1981. Water quality in agricultural watersheds: Impact of riparian vegetation during base flow. *Water Resources Research* 17(2):233-40.

Schwarz, Loring LaB. 1993. *Greenways: A Guide to Planning, Design, and Development*. Edited by Flink, Charles A. and Robert M. Searns. Covelo, Calif.: Island Press.

Sedell, James R. and Judith L. Froggatt. 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U S A, from its floodplain by snagging and streamside forest removal. *Verh. Internat. Verein. Limnol.* 22:1828-34.

Shrubsole, Dan. 1992. The Grand River Conservation Commission: history, activities, and implications for water management. *The Canadian Geographer* 36(3):221-236.

Slocombe, D Scott. 1993. Implementing ecosystem-based management. *BioScience* 43(9):612-622.

Smith, Daniel S. 1993. An overview of greenways: their history, ecological context, and specific functions. In *Ecology of Greenways: Design and Function of Linear Conservation Areas*, edited by Smith, Daniel S and Paul Cawood Hellmund. (Minneapolis: University of Minnesota Press).

Smith, Daniel S and Paul Cawood Hellmund. 1993. *Ecology of Greenways: Design and Function of Linear Conservation Areas.* Minneapolis: University of Minnesota Press.

Smith, John W., Zulhizzan Ishak-Muhamad, and Ewe Leng Lim. 1990. Utility of a GIS in watershed management- A case study. In *Watershed Planning and Analysis in Action*, edited by Riggins, Robert E., E. Bruce Jones, Ranvir Singh, and Paul A. Rechard. (New York: American Society of Civil Engineers).

Spies, T A, W J Ripple, and G A Bradshaw. 1994. Dynamics and pattern of a managed coniferous landscape in Oregon. *Ecological Applications* 4:555-568.

Squires, Donald F. 1992. Quantifying anthropogenic shoreline modification of the Hudson River and estuary from European contact to modern time. *Coastal Management* 20:343-54.

Starbird, Ethel A. 1972. A river restored: Oregon's Willamette. *National Geographic* 141(6):816-835.

Stoddart, David Ross. 1986. *On geography and its history.* New York: B. Blackwell.

Stow, D A. 1993. The role of geographic information systems for landscape ecological studies. In *Landscape Ecology and Geographic Information Systems*, edited by Haines-Young, Roy H., David R. Green, and Steven Cousins. (London: Taylor & Francis).

Swanson, Frederick J., Stanley V. Gregory, James R. Sedell, and A. G. Campbell. 1982. Land-water interactions: the riparian zone. In *Analysis of Coniferous Forest Ecosystems in the Western U. S.*, edited by Edmonds, Robert L. (Stroudsburg, Penn.: Hutchinson Ross Publishing Co).

Tabacchi, Eric, Anne-Marie Planty-Tabacchi, and Odile Décamps. 1990. Continuity and discontinuity of the riparian vegetation along a fluvial corridor. *Landscape Ecology* 5(1):9-20.

Theobald, David M. and N. Thompson Hobbs. 1998. Forecasting rural land-use change: a comparison of regression- and spatial transition-based models. *Geographical & Environmental Modelling* 2(1):65-82.

Thomas, William L Jr. Man's Role in Changing the Face of the Earth. 1956. Chicago, University of Chicago Press.

Thorne, James F. 1993. Landscape ecology. In *Ecology of Greenways: Design and Function of Linear Conservation Areas*, edited by Smith, Daniel S and Paul Cawood Hellmund. (Minneapolis: University of Minnesota Press).

Towle, Jerry C. 1982. Changing geography of Willamette Valley woodlands. *Oregon Historical Quarterly* 83(1):67-90.

Turner, B. L. II and W. B. Meyer. 1994. Global land-use and land-cover change: an overview. In *Changes in Land Use and Land Cover: A Global Perspective*, edited by Meyer, W. B and B. L. II Turner. (Cambridge: Cambridge University Press).

Turner, B. L. II, William B. Meyer, and David L. Skole. 1994. Global land-use/land-cover change: towards an integrated study. *Ambio* 23(1):91-95.

Turner, Monica G., David N. Wear, and Richard O. Flamm. 1996. Land ownership and land-cover change in the southern Appalachian highlands and the Olympic peninsula. *Ecological Applications* 6(4):1150-1172.

Turner, Monica Goigel. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* 20:171-197.

Turner, Monica Goigel and C. Lynn Ruscher. 1988. Changes in landscape patterns in Georgia, USA. *Landscape Ecology* 1(4):241-51.

Valladares, Miguel Angel. 1993. Effects of EC policy implementation on natural Spanish habitats. *The Science of the Total Environment* 129:71-82.

Vannote, Robin L., G. Wayne Minshall, Kenneth W. Cummins, James R. Sedell, and Colbert E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Science* 37:130-37.

Vogelmann, J. E., T. Sohl, and S. M. Howard. 1998. Regional characterization of land cover using multiple sources of data. *Photogrammetric Engineering & Remote Sensing* 64(1):45-57.

Wear, David N. and Paul Bolstad. 1998. Land-use changes in Southern Appalachian landscapes: spatial analysis and forecast evaluation. *Ecosystems* 1:575-594.

Wear, David N., Rei Liu, J. Michael Foreman, and Raymond M. Sheffield. 1999. The effects of population growth on timber management and inventories in Virginia. *Forest Ecology and Management* 118:107-115.

White, Gilbert F. 1972. Environmental impact statements. *The Professional Geographer* 24(4):302-309.

White, Gilbert F. 1977. *Environmental Effects of Complex River Development.* Boulder: Westview Press.

White, Richard. 1995. *The Organic Machine.* New York: Hill and Wang.

Wickramaratne, Siri Nimal. 1983. Vegetation changes in the Willamette River Greenway, Benton and Linn counties, Oregon, 1972-1981. Oregon State University Department of Geography, Corvallis, Oregon.

Willamette Riverkeeper. Riverlands Report. 1996.

Williams, Donald C. and John G. Lyon. 1997. Historical aerial photographs and a geographic information system (GIS) to determine effects of long-term water level fluctuations on wetlands along the St. Mary's River, Michigan, USA. *Aquatic Botany* 58:363-378.

Wilson, Mark Shelton. 1994. Origins of the Old-growth Forest Conflict (1971-1989): A New Model for Resource Allocation. Oregon State University Department of Geography, Corvallis, Oregon.

Wright, Andrea, W. Andrew Marcus, and Richard Aspinall. 2000. Evaluation of multispectral, fine scale digital imagery as a tool for mapping stream morphology. *Geomorphology* 33:107-120.

CHAPTER 2

GIS METHODOLOGY FOR CHARACTERIZING HISTORICAL CONDITIONS OF THE WILLAMETTE RIVER FLOODPLAIN, OREGON

Doug R. Oetter, Linda R. Ashkenas,
Stanley V. Gregory, Paula J. Minear

Manuscript to be submitted to:

Transactions in GIS
Blackwell Publishers, Oxford

ABSTRACT

Recent environmental developments in the Willamette Valley have stimulated an interest in conservation and restoration of the historic river floodplain, both to protect against flooding and to provide wildlife habitat. In order to best utilize scarce resources, historic and present floodplain and river channel conditions were characterized to help prioritize the best restoration sites. Using a variety of data sources, a Geographic Information System (GIS) was developed to accomplish this task. Line and polygon coverages were constructed to map active channels, side channels, islands and tributaries for four separate dates, as well as riparian and floodplain vegetation at two times. Coverages based on flood records and other boundaries were used to partition the floodplain into spatial subsets for analysis. The GIS allowed comparisions between historic and present conditions for a variety of environmental factors. Much of the historic channel complexity and floodplain forest has been removed since 1850. Selected river and floodplain variables were made available to develop a spatial model to prioritize potential locations for floodplain restoration.

Keywords: floodplain, geographic information system (GIS), historic mapping, river restoration, Willamette Valley, Oregon.

INTRODUCTION

One of the signs of progressive environmental management is the ability to incorporate modern techniques to solve problems born out of a long legacy of ecological change. A series of events surrounding the Willamette River in northwest Oregon has recently inspired new directions in floodplain management which may provide opportunities to subtantially improve environmental conditions in a variety of ways. Floodplain restoration has been proposed through a joint effort among public and private entities to achieve many environmental management goals (Willamette Riverkeeper 1996; Gardiner 1999). The proposal is to reclaim riparian farmlands to allow replanting of native floodplain forests and recovery of riparian wetlands. Among the many potential benefits of restoration are flood control and habitat improvement, concerns made more crucial following a major flood event in 1996 as well as the continued decline of anadromous salmon runs on the Willamette River. Scientific research to support floodplain restoration in the Willamette Valley has now gained considerable momentum, concurrent with increasing public regard for pollution, recreation, scenic, and wildlife issues along the Willamette River (WRI 2001).

There are a variety of ecological, geomorphological, and hydrological connections between rivers and their floodplains (Petts et al. 1992; Malanson 1993; Large and Petts 1996; Newson 1997). Most of the ecological qualities of a river are directly influenced by its surrounding landscape as well as the human activities that the landscape support (Decamps et al. 1988; White 1995; Naiman et al. 1988; Gurnell 1997b; Ward et al. 1999). In addition, a river has a direct influence on its surroundings, frequently altering the physical and biological conditions of its floodplain (Shankman 1993; Brookes 1996). Current science supports the notion of a river as a complex dynamic physical and ecological system, with a necessary level of natural integrity required to function effectively (Gregory et al. 1991; Graf 2001). There are significant economic and ecological advantages to be gained from the restoration of large river floodplains (Bayley 1995), and the science of floodplain restoration is developing rapidly (Boon et al. 1992; NRC-CRAE 1992; Sedell et al. 1992; Schiemer et al. 1999).

The capacity of a Geographic Information System (GIS) to portray, analyze, and model spatio-temporal information makes it ideal for river floodplain studies (Iverson and Risser 1987; Lam 1989; Allen 1994; Muller 1997). Many aspects of floodplain management have been enhanced by the incorporation of a GIS, including riparian buffer analysis and delineation (Narumalani et al. 1997; Moser et al. in press), channel planform change (Doward et al. 1994; Mossa and McLean 1997; Gurnell 1997a; Winterbottom and Gilvear 2000), and floodplain vegetation change (Johnson et al. 1995; Allen 1999; Dixon and Carter 1999; Gutowsky 2000). A GIS can integrate spatial data from a variety of sources, and this feature enhances location models which rank potential restoration sites based on numerous economical, ecological, and physical variables (Llewellyn et al. 1996; Russell et al. 1997; Iverson et al. 2001).

Study area

The Willamette River basin provides an ideal setting to develop the principles of floodplain restoration (Figure 2.1). The Willamette is the thirteenth largest river in the United States, with a mean annual flow of 900 cm^3/s below Portland (Willamette Riverkeeper 1996). It drains a 29,700 km^2 basin which is dominated by intensively managed upland forests in the Cascade and Coast Range mountains and highly productive agricultural fields throughout the valley floor. Only 6% of the basin area is occupied by urban land cover, yet that land houses over 2.4 million people (67% of Oregon's population). The Willamette valley is over 175 km long and about 40 km wide, and consists of deep Missoula flood silts broken by volcanic remnants (Hulse et al. 2002).

The Willamette River drains fractured basalt lava flows in the Cascade mountains and descends through heavily wooded Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) forests to its valley floor, where it continues north to the Columbia River through thick riparian hardwood forests of alder (*Alnus* spp.), willow (*Salix* spp.), bigleaf maple (*Acer macrophyllum*), Oregon ash (*Fraxinus latifolia*), Oregon white

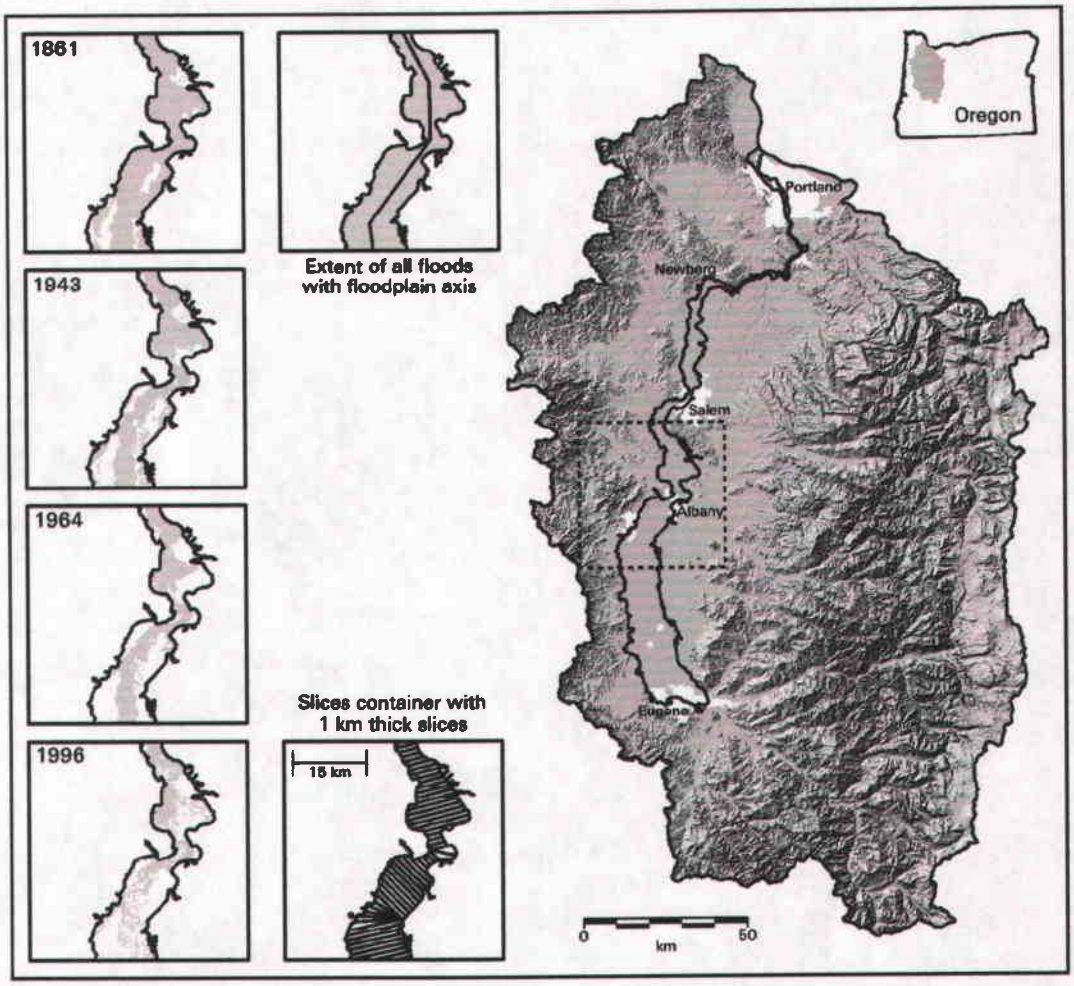

Figure 2.1. Creation of the slices analysis coverage from four flood extent maps for multiple years is shown for the Willamette River basin in northwest Oregon.

oak (*Quercus garryana*), black cottonwood (*Populus trichocarpa*) and others (Towle 1982). Flowing across numerous gravel-lined channels in its upper stretches from Eugene to Albany, the river cuts through sedimentary deposits in its middle stretch from Albany to Newberg, and then enters a high constrained lower reach from Newberg Pool over the Willamette Falls to Portland (Figure 2.1). After passing Portland, it leaves the Willamette Valley and enters the Columbia River over 500 km from its source at Waldo Lake (Sedell and Froggatt 1984; Dykaar and Wigington 2000).

The modern Willamette River has changed dramatically since the initial settlement of the valley by Europeans in the 1830s. The extensive floodplain hardwood forests were removed, both to fuel steamboats and to clear land for agriculture. The braided gravel channels in the upper reaches of the valley were channelized and their river banks hardened by revetments and other structures. As a result, the river system is much less complex than it was 150 years ago, with almost 50% of the historical channels removed from some portions of the river network (Sedell and Froggatt 1984; Benner and Sedell 1997). Thirteen tributary dams now regulate the river, reducing the frequency and severity of major floods, and removing sediments from the river downstream, a process which allows downcutting of the river and further inhibits overflow events (Dykaar and Wigington 2000). Riparian vegetation, which was once in a dynamic equilibrium with flooding, now appears to be stabilizing as a mature hardwood forest, with disturbance made more difficult by a lack of overbank events (Gutowsky 2000). In addition, the river is still recovering froma century of human pollution, especially from cities and pulp mills. In the 1930's the river's water quality was so bad that anadromous salmon could barely survive the swim through Portland harbor because of precipitously low dissolved oxygen content (Willamette Riverkeeper 1996; Mullane 1997). Only through aggressive efforts in the last 40 years has the water quality recovered to make recreational use of the river again feasible. Such efforts were rewarded by the designation of the Willamette in 1998 as one of the 14 initial American Heritage Rivers (Gardiner 1999).

The combination of events surrounding the Willamette River's recovery has led many scientists and politicians to call for a continued recovery plan which would include restoration of historic floodplain (Frenkel et al. 1991). In 1998, the Willamette Restoration Initiative was established by State Executive Order 98-18 to develop a "basinwide strategy to protect and restore fish and wildlife habitat, increase populations of declining species, enhance water quality, and properly manage floodplain areas- all within the context of human habitation and continuing basin growth (WRI 2001: ii)." The restoration effort has been joined by the U. S. Army Corps of Engineers (ACOE), which has funded a floodplain restoration feasibility study (Gardiner 1999), as well as the U. S.

Fish and Wildlife Service, which has acquired riparian farmland for restoration to native forests and wetlands. One important task is to determine which floodplain lands are most ideal for restoration (NRC-CRAE 1992; Gregory 1999).

Objectives

In the face of limited funding and given an expansive floodplain, decision makers required a scientific method of prioritizing floodplain restoration efforts (Gregory 1999). A GIS was developed to characterize the historic floodplain and to help select potential areas for riparian restoration.

The goal of this research was to develop GIS methodologies for the temporal analysis of the floodplain, keeping in mind the requirements of a spatial model that would identify potential areas for riparian restoration. The purpose of this paper is to present the GIS methodology for characterizing historic and present-day floodplain conditions. The major results of the historical analysis and restoration modeling are beyond the scope of this paper, and are presented elsewhere (Hulse et al. 2002; Gregory et al. in review). It is important to note that not all the figures presented here will match exactly those presented in other works as some specific analysis methods may have been conducted separately.

METHODS

There were three basic steps to the methodology. First, polygons coverages to define the study area (based on the functional extent of the floodplain) and sub-regions of interest were created. Then, the river channel extents were mapped at four separate dates. Finally, the floodplain vegetation for two periods with reliable land cover data was mapped. After the creation of these spatial data layers, the GIS was available for queries to produce numerical data for the generation of tables, graphs, and GIS-based output maps, as well as to drive a restoration siting model.

Generation of floodplain extent

Because of the linear nature of rivers, a useful technique for describing floodplain features is to partition the floodplain into segments along the length of the river (Downward et al. 1994; Mossa and McLean 1997; Gurnell 1997a). Structuring the floodplain in this manner allows comparision of upstream and downstream characteristics, which can vary widely depending on channel slope, channel constrictions, and other other geomorphological considerations (Petts and Calow 1996). Furthermore, using the floodplain length instead of river length allows consistency over time, since river distances change regularly. For this study, the floodplain was delineated based on the historical flood record, and then for analytical purposes this area was subdivided into longitudinal sections, or slices, along the length of the floodplain (based on suggestions from Dr. Herve Piegay , Université Lyon, 18, rue Chevreul, 69007 Lyon, France).

The floodplain extent was determined using historical flood maps created by the U. S. Army Corps of Engineers (ACOE) for major floods in 1861 (the largest on record), 1943, and 1964. These paper maps were based on eyewitness reports, photographs, high water marks, and other information. As part of the Willamette River Historical Flood Mapping Project, sponsored by the U. S. Fish and Wildlife Service, the maps were digitized as vector polygon coverages denoting the spatial extent of floodwaters. For a fourth flood in February 1996, a detailed digital coverage was obtained from the ACOE based on aerial photography acquired during the flood. A combined flood extent layer was created from the spatial union of the four floods, with most internal ' islands' (areas of higher ground that were not underwater but were completely surrounded by floodwater) removed to create an unbroken boundary (Figure 2.1).

Following the delineation of the maximum lateral floodplain extent, a coverage was created to subdivide the entire floodplain into 227 unequal sections defined by normal lines perpindicular to the floodplain axis intersected at 1-km transect points (Figure 2.1). The floodplain axis was drawn to maximize separation of the floodplain into longitudinal segments, which could then be used to divide the floodplain into significant reaches. Where the axis changed directions, irregular wedge-shaped slices were formed.

These transitional slices, where the floodplain axis changes direction, created interpretation problems due to their irregular shape, and so they were labeled as 'corners' for identification during analysis. The coverage required hand editing to attribute and to adjust, including expanding it in places where the river channel cut very close to the edge of the floodplain, so that it would include buffer coverages of those channels.

In addition, two other analysis containers were created. The first was the 100-year floodplain as defined by Federal Emergency Management Agency (FEMA) National Flood Insurance Program maps (http://www.fema.gov/mit/tsd/). Digital forms of these maps were appended, edgematched, and then reselected for 100-year floodplain. The last container was the boundary of the Willamette River Greenway (WRG), as drawn on paper maps (ODOT 1976). The WRG is a land use designation created by state legislation to restrict non-essential land development within immediate proximity of the river. To translate the greenway boundary into a digital coverage, the linework was screen digitized over a collection of 1995-era digital orthophotographs.

Channel mapping

The next phase of the methodology was to map the historical extent of the river channel. This was done for four different time periods using separate data sources and approaches (Figure 2.2). For each period, the active channels of the river were mapped and each main channel, secondary or side channel, tributary, alcove, and island was labeled .

The initial channel mapping effort was based on detailed interpretation of General Land Office (GLO) survey records (Schulte and Mladenoff 2001), done by the Oregon Natural Heritage Program (Christy and Alverson in preparation). While laying out the township and range boundaries for the Willamette Valley, GLO surveyors measured the location of the river channels and main tributaries that crossed boundaries and noted positions within the section. In most cases, their plat maps included line drawings indicating the location of both banks for the rivers and single lines for the streams.

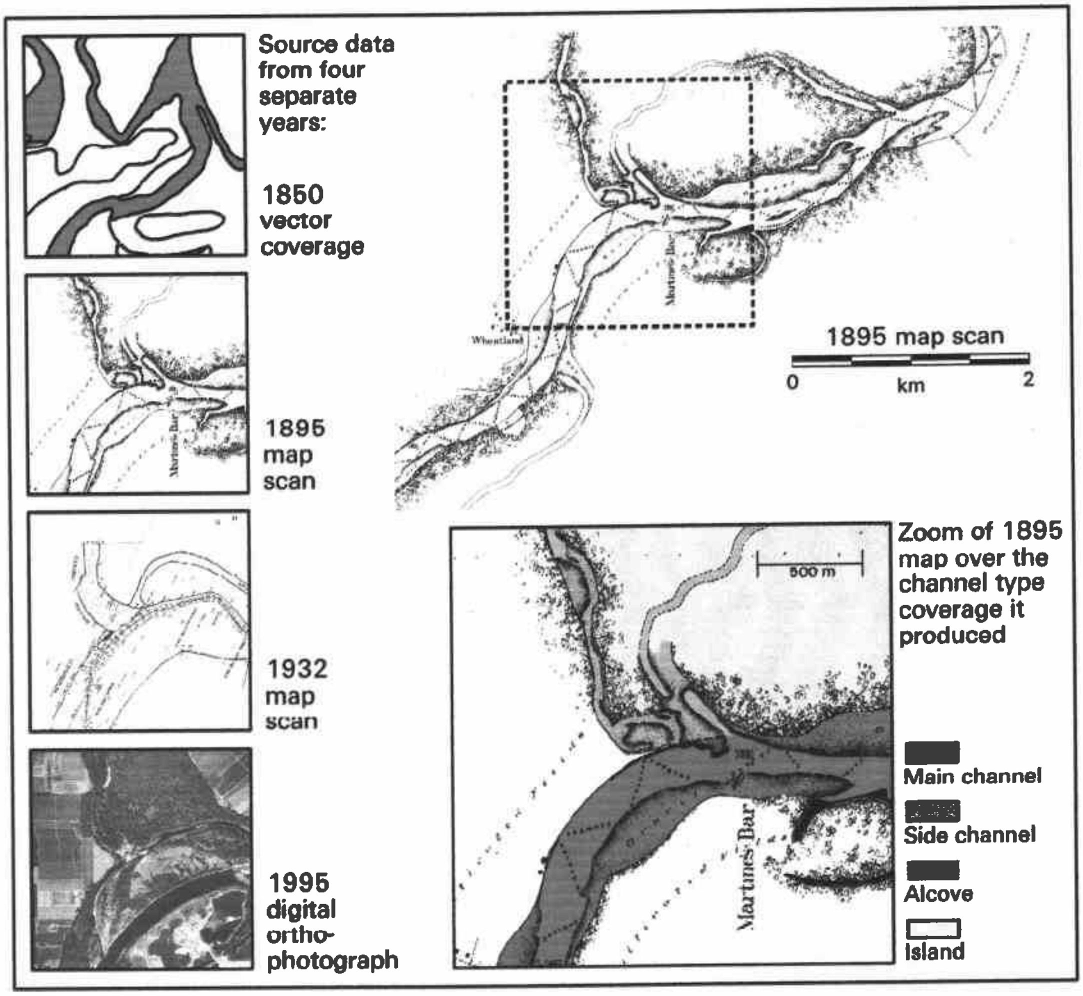

Figure 2.2. Development of channel maps from different sources of spatial data for 1850, 1895, 1932, and 1995.

Skilled technicians interpreted those maps and survey reports to detail the boundaries of the significant water bodies in the valley. This linework was then converted to a vector coverage using a digital version of the township and range grid as a reference. While it took forty years from 1850 to 1890 to survey the entire valley (Christy and Alverson in preparation), the townships near the river were finished in the first ten years, so the initial date was assigned to the channel map derived from this source.

The ACOE conducted thorough surveys of the Willamette River in 1895 and 1932, and created a series of navigation-grade maps for each date (ACOE 1895; ACOE

1932). The 1895 series consisted of 15 maps at 1:12000 scale. In 1932 the ACOE used a scale of 1:5000, which required 52 maps to cover the river from Eugene to Portland. Paper copies of these maps obtained from the Oregon State Archives were scanned into Tagged Image Format (.tif) files. Those images were imported into GIS software as raster files and georectified to a common geographic reference system using the township and range registration marks drawn on the maps and some permanent features (rock formations, bridges, ferry crossings, etc.). The map elements were then converted to digital coverages using an automated pattern recognition tool (ESRI ArcScan) and a significant amount of screen digitizing and attributing. From these two series of maps, coverages for river active channel (or high flow), river low flow channel, river maximum depth, river structures (dams, spillways, etc…), riverbank roads and railroads, and riverbank vegetation were created.

To map the 1995 river channel, black and white digital orthophotographs were used as source images for screen digitizing. Initially, 164 separate images at a pixel resolution of 0.67 m were mosaicked and reprojected to a base projection. The channel features and other water bodies were screen digitized and attributed using visual reference. Where the high water line was obscured by clouds or other feature, expert judgment was used to continue the digitizing, often with ancillary photography or field reference.

For each of these four dates, a river thalweg line coverage was screen digitized on the active channel to identifiy the main channel and provide a reference for river length. For 1850, there was no depth information from the GLO survey, so the thalweg was located at the channel centerline. The ACOE river survey maps from 1895 and 1932 included depth soundings, which were useful in delineating the main channel. For 1995, the thalweg was screen digitized over the digital orthophotographs, using expert judgment to determine the main channel. The thalweg coverage was coded to indicate channel complexity by labeling each segment as either single channel, multiple channel, or tributary junction (minimum length for coding was 500 m) (Figure 2.3). In addition, the thalweg was similarly coded to indicate the presence of revetments or wing dams on one or both banks as a measure of structural complexity.

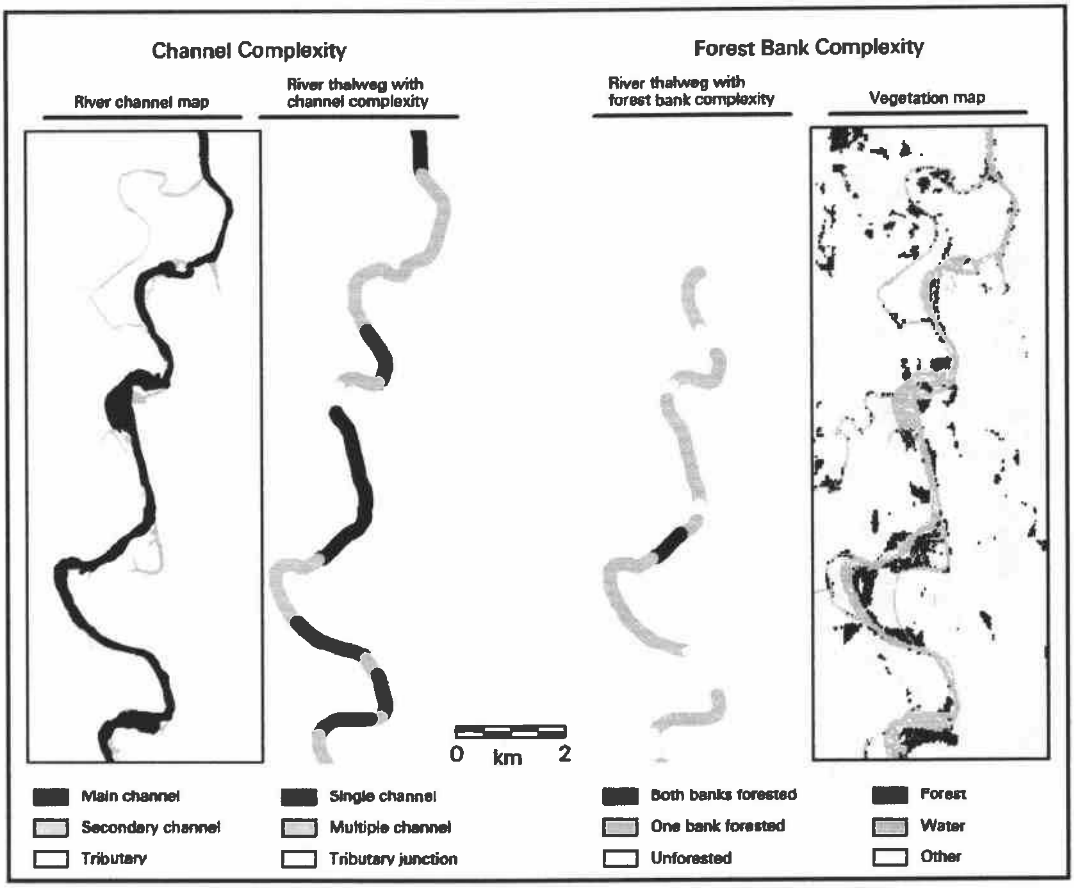

Figure 2.3. Derivation of 1995 channel and forest bank complexity attributes attached to the thalweg. Each river length was coded to indicate the complexity at that point.

Floodplain vegetation mapping

Vegetation cover for the floodplain was characterized for two dates, 1850 and 1995. Ideally, this would have been done for 1895 and 1932 as well, but the ACOE river survey maps only included scant descriptions of streambank vegetation, and complete land cover data for the entire floodplain were not available.

The 1850 land cover characterization was generated by the same process used to transcribe the 1850 channel maps, using the GLO plat maps and survey notes (Christy and Alverson in preparation). The interpreters mapped the Willamette valley for 55 different land cover classes, based on the detailed descriptions of surveyors, as well as modern topographic and soils maps. Their linework was developed as a polygon coverage which was rasterized to 25 m pixels to match the 1995 vegetation map.

The 1995-era data came from a land cover/land use map developed for a regional project , funded by the U. S. Environmental Protection Agency (Hulse et al. 2002). The primary source for the map was a multi-temporal Landsat Thematic Mapper data set from 1992, interpreted into 40 different land cover classes at 25 m pixel resolution (Chapter 3). This base map was then amended and enhanced by the addition of geospatial information and GIS coverages for agricultural fields, census data, transportation routes, land use zoning, and water bodies to produce a 58-class land use/land cover map.

To make effective comparisons between the two land cover data sources, each 1850 land cover code was cross-referenced to a modern code (Hulse et al. 2002). This procedure required several assumptions to reconcile detailed nineteenth-century ground-level notes with the broad land cover classes derived from modern remote sensing imagery. For example, community-level subclasses of prairie and savanna were collapsed into one very broad class named 'natural shrub and grasslands.' Woodland classes were cross-referenced to open and semi-open forest. Further details can be found in Hulse et al. (2002).

To address riparian management issues, it was important to map floodplain vegetation not only for the entire floodplain, but also only along the streambanks, as an indicator of riparian land cover. For both 1850 and 1995, the river channel coverages were buffered away from the water (inward buffer for islands) to capture pixels immediately adjacent to the water. A similar procedure was used to capture pixels within a 'riparian zone of influence' (Gregory et al. 1991), which was defined as the area within 30 and 120 m of the channel edge. To locate the riparian pixels of interest, raster masks based on the channel vector coverages were created, and then used to query vegetation cover images.

For each of the four dates, streambank vegetation descriptions were used to generate a forest bank complexity index. The river thalweg was attributed to indicate the presence of riparian forest on none, one, or both banks. This allowed a direct comparison for riparian forest cover for the four dates, including 1895 and 1932, which lacked areal floodplain data (Figure 2.3).

RESULTS

The GIS approach to mapping historic and current floodplain conditions in the Willamette River floodplain produced a vast quantity of information; each of the 227 river slices was queried across the four dates for channel type and area, streambank vegetation, channel complexity, structural complexity, and forest bank complexity. A brief synopsis of the results is presented here to demonstrate the GIS approach. A more in-depth ecological explanation of the findings can be found in Hulse et al. (2002) and Gregory et al. (in review).

Seven separate analysis containers were produced to analyze floodplain features (Table 2.1). The first four were flood extents, with the largest being that of the 1861 flood. By many accounts, the 1861 flood may have been the largest Willamette flood in post-settlement history (Hulse et al. 2002). In addition, the 1861 flood extent coverage was derived from a map based largely on extrapolation of historical information, so some smoothing likely occurred. The smallest flood extent was the 1996 flood, which resulted from a variety of factors, including the effectiveness of flood control projects, the improved precision of modern photo-based mapping techniques, and the fact that the 1996 flood was simply not as large as many earlier floods. For each of the flood extent maps, the majority of inundated land was found in the upper reach of the river, between Eugene and Albany, where the floodplain is broad and flat and there are few channel constrictions. In the lower reach, from Newberg to below Portland, the river is downcutting through bedrock, and as a result has a very narrow floodplain and concomittant small flood extents.

Table 2.1. Reach and total areas (ha) of seven different spatial analysis coverages within the study area.

Coverage	River Reach Lower (km 1-71)	Middle (km 72-151)	Upper (km 152-227)	Total
1861 flood [1]	2819	34936	70020	107774
1943 flood [2]	3205	30754	49500	83459
1964 flood [3]	4134	26269	26344	56747
1996 flood	4341	21390	11586	37317
Slices	7173	36906	82208	126287
FEMA	3818	28581	40425	72823
WRG	7659	7467	7184	22310

1- The 1861 flood map was incomplete for floodplain slices 1-40.
2- The 1943 flood map was incomplete for floodplain slices 1-26.
3- The 1964 flood map was incomplete for floodplain slices 1-5.

A union of the four flood extent maps was used to create a fifth coverage, named slices, which segmented the entire floodplain extent into 227 sections. Twenty-five (fewer than 10%) of the slices were located at points where the floodplain axis changed direction. These irregular slices represent only 6.5% of the coverage area. The slices coverage is only 17% larger than the 1861 flood extent, which indicates that much of the floodplain area defined for this study was derived from that coverage. The slices coverage is larger because unflooded areas surrounded by floodwaters from each flood coverage were included in the maximum flood extent. The mean floodplain slice is 556 ha; if each slice was 1 km long, this would suggest a mean slice (and floodplain) width of 5.6 km.

The sixth container is the FEMA 100-year floodplain coverage, based on post-dam estimates. The FEMA coverage shows lands restricted by special zoning ordinances within the 100-year floodplain, which may be more promising for conservation or restoration. The final analysis container was the 1976-era Willamette River Greenway boundary. As a special use land zoning boundary, this coverage contained the the least area, and was used for analysis specific to that designation.

For each of the four channel mapping dates, results for diversity of channel types and areal coverage of each channel type were tabulated by floodplain slice (Table 2.2). The greatest number and extent of channels was found in the upper reach in 1850.

Because of channelization and flood control, the number of channels in this reach dropped dramatically by 1995. In the lower reach, the historical impact on channels was less, partly because the floodplain was historically geologically confined.

The simplification of the Willamette River over time was further evidenced by the channel and forest bank complexity analysis (Table 2.3). From 1850 to 1990, multiple channel lengths decreased by almost 40%, while single channels increased. Again, the channel change in the upper reach was the most dramatic. The length of river with forests on both banks dropped as well, by over 75% along the whole river. Over 360 separate structures, covering over 50% of the river's length, were built from 1850 to 1995 (Hulse et al. 2002). These installations are part of the reason for the decline in channel and forest extent.

The floodplain vegetation analysis was performed for 1850 and 1995; simplified results are shown in Table 2.4. Overall, the trend has been towards replacement of the native floodplain vegetation, especially riparian hardwood forests and prairies, with agriculture and urban land cover types. A similar trend was observed with streambank vegetation, indicating that forest removal also occured along the riverbanks. The riparian forest complexity results also demonstrated that much of the riparian forest was removed by 1895 and has not regrown. More detailed analysis allowed determination of which floodplain slices had the greatest changes. A wide variety of explanatory graphics, tables, and maps were produced for the detailed report (Hulse et al. 2002).

DISCUSSION AND CONCLUSIONS

The main goal for this research was to develop a mapping method to compare floodplain and river channel features across time periods. This was achieved by developing a GIS to create and analyze spatial data from four dates spanning 150 years. While each year had a different source of data, channel and floodplain characteristics were compared directly over time by creating georegistered river channel and floodplain vegetation coverages. The use of spatial containers allowed for the subdivision of the

Table 2.2. Summary of lengths and areas for channels and islands in the Willamette River floodplain from 1850-1995.

Reach	Length (km)				Area (ha)				
	Primary Channel	Side Channel	Alcove	Total	Primary Channel	Side Channel	Alcove	Island	Total
Lower (km 17-51; Portland-Newberg)[1]									
1850	60	6	2	68	1473	110	11	121	1714
1895	60	13	0	73	1480	176	3	154	1813
1932	58	14	0	72	1630	166	0	155	1952
1995	60	15	1	76	1405	168	2	118	1694
% change 1850-1995	-1.0	139.9	76.9	10.8	-4.6	53.6	-80.0	-2.5	-1.2
Middle (km 52-151; Newberg-Albany)									
1850	115	35	14	163	2409	310	82	1946	4746
1895	112	47	22	181	2957	369	125	2084	5535
1932	115	39	10	163	2608	372	74	1945	4999
1995	114	34	15	163	2117	207	69	1778	4171
% change 1850-1995	-0.9	-2.1	10.8	-0.2	-12.1	-33.1	-15.5	-8.6	-12.1
Upper (km 152-227; Albany-Eugene)									
1850	118	193	28	339	1948	1060	177	6899	10084
1895	99	118	22	238	2109	939	138	4747	7933
1932	99	131	22	252	1865	723	70	3686	6344
1995	100	50	35	185	1534	281	103	1414	3333
% change 1850-1995	-14.7	-74.0	21.7	-45.4	-21.3	-73.5	-41.4	-79.5	-66.9
Total (km 17-227; Portland-Eugene)									
1850	293	234	44	571	5829	1480	269	8966	16544
1895	271	177	44	492	6546	1484	267	6985	15282
1932	272	183	32	487	6104	1262	144	5787	13296
1995	275	99	50	424	5056	658	175	3309	9197
% change 1850-1995	-6.1	57.7	13.1	25.8	-13.3	-55.6	-35.1	-63.1	-44.4

1- Data sources for 1895 and 1932 were incomplete below Portland, so floodplain slices 1-16 are excluded from all years in this table.

Table 2.3. Summary of changes in channel characteristics for the Willamette River from 1850-1995.

	Channel complexity [1]			Forest bank complexity [2]				Structural complexity [3]	
	Single channel	Multiple channel	Tributary junction	Unforested riverbank	One bank forested	Both banks forested	Total thalweg length (km)	Number of structures	Length of structures (km)
Lower reach (km 1-51; Columbia R. to Newberg)									
1850	63521	7662	3876	2150	32027	40883	75.1	0	0.0
1995	61501	10098	3285	38893	29139	6852	74.9	138	62.4
Percent change	-3.2%	31.8%	-15.3%	1709.3%	-9.0%	-83.2%	-0.2%	-	-
Middle reach (km 52-151; Newberg to Albany)									
1850	88321	24022	2562	1604	38188	75113	114.9	0	0.0
1995	79519	29115	3458	21983	59700	30409	112.1	117	35.3
Percent change	-10.0%	21.2%	35.0%	1270.6%	56.3%	-59.5%	-2.4%	-	-
Upper reach (km 152-227; Albany to Eugene)									
1850	37954	82758	3815	0	25679	98848	124.5	0	0.0
1995	72194	30355	3003	44653	47771	13127	105.6	113	57.3
Percent change	90.2%	-63.3%	-21.3%	-	86.0%	-86.7%	-15.2%	-	-
Total (km 1-227; Columbia R. to Eugene)									
1850	189796	114442	10252	3754	95894	214844	314.5	0	0.0
1995	213214	69569	9745	105530	136610	50389	292.5	368	155.0
Percent change	12.3%	-39.2%	-4.9%	2711.4%	42.5%	-76.5%	-7.0%	-	-

1. Channel complexity is the length of thalweg in meters associated with either single channels, multiple channels, or a tributary junction.
2. Forest bank complexity is the length of thalweg in meters associated with either unforested bank, forest on one bank, or forest on both banks.
3. Structural complexity is the length of thalweg in meters with revetments or other structures along either bank.

Table 2.4. Summary of changes in riparian vegetation (up to 120 m from riverbank) for the Willamette floodplain from 1850-1995. Totals vary because of an overall loss of channels.

		Riparian land cover (ha)					
		Agriculture	**Urban**	**Forest**	**Wetland**	**Other Natural**	**Total**
Lower reach (km 1-51)	1850	0	0	1085	47	743	1875
	1995	102	810	326	2	86	1326
	% change	-	-	-70.0%	-95.7%	-88.4%	-29.3%
Middle reach (km 52-151)	1850	0	0	3495	64	1076	4635
	1995	2777	437	1621	99	934	5868
	% change	-	-	-53.6%	54.7%	-13.2%	26.6%
Upper reach (km 152-227)	1850	0	0	7019	233	1846	9098
	1995	4512	791	1253	154	1157	7867
	% change	-	-	-82.1%	-33.9%	-37.3%	-13.5%
Total	1850	0	0	11599	344	3665	15608
	1995	7391	2038	3200	255	2177	15061
	% change	-	-	-72.4%	-25.9%	-40.6%	-3.5%

entire floodplain into analysis units that were useful both for analysis and for reporting results.

The floodplain has changed drastically since European settlement, but the magnitude of those changes varies among the river floodplain reaches. Agreeing with Benner and Sedell (1997), it was clear that the number of channels in the floodplain has been greatly reduced. Channel complexity was once highest in the upper reach of the river (from Eugene to Albany), and so this is where the greatest simplification has occurred. In addition, floodplain forests which were prevalent along the river banks in 1850 have all but been removed. In all three reaches of the river, forest bank complexity has been reduced and native floodplain has been replaced with agricultural fields and other human developments. The lower reach, from Newberg to below Portland, saw the least channel change and floodplain alteration, but this is primarily because this reach of the river is highly constricted topographically and was historically less complex. Much of the channel change and riparian vegetation removal occurred over 100 years ago, during an aggressive period of river modification (Hulse et al. 2002).

The GIS can be used to quantify potential for conservation and restoration of each floodplain slice, based on the calculation of socioeconomic and biophysical indices (Hulse et al. 2002; Hulse and Gregory 2001). The relatively simple model formulation was based on the assumption that the best sites for restoration would be in floodplain slices that were not overly developed and had also seen high levels of historic floodplain complexity. The model is flexible in that the threshold for suitable slices can be adjusted to suit new criteria. In fact, all 227 slices could be ranked by either index or a combination of the two. While it is highly unlikely that riparian forests and floodplain channels will be returned to their historic levels of abundance, opportunites exist along the entire length of the mainstem river for either recovery or preservation of existing channel complexity.

This research project was ideally suited to a GIS approach. In fact, it is difficult to imagine how the tasks could have been accomplished without using a GIS. Forgoing the expense of software and training (Harris et al. 1997), the GIS methodology allowed us to characterize fine-scaled landscape details across a large area over four different time periods. There were errors associated with geographic registration, however, those errors were small in relation to spatial misregistration in the original data. As well, there were certainly errors associated with converting the GLO surveys and ACOE river maps and digital orthophotographs into digital line work. While the complete accuracy and reliability of our data remain unknown, our sources were the best available and are acceptable for regional analysis.

Perhaps the greatest advantage of using a GIS for this research was the flexibility of having the data in digital form (Downward et al. 1994; Russell et al. 1997). Using identity and zonal functions in the GIS software, digitial summary estimates of length and area were easily manipulated into spreadsheet software to produce graphs and tables, and to generate the restoration indicies. Mapping floodplain change with a GIS enabled the employment of spatially explicit algorithms for more detailed analyses (Muller 1997). An added advantage was the ability to switch the focus of the study rapidly by replacing the slices coverage with one of the other container coverages. In all, there were seven different analysis containers with which to summarize floodplain characteristics. In addition, the digital data are preserved indefinitely and can be re-analyzed repeatedly by different researchers with different analysis goals.

The major shortcoming of the GIS approach has to do with the digitization and registration of the source data, both of which required extensive manual effort. Although some steps were automated, the conversion of spatial information from paper maps to digital form requires careful manipulation and much attention to detail., both of which require trained operator time and expense.

In summary, the research goals were achieved by the application of GIS techniques to data creation and analysis for a complex historical floodplain environment. Without the GIS, it would have been very difficult to integrate the wide variety of source data available or to model and query a spatial extent as large as the Willamette River floodplain. The GIS approach enabled the creation of a digital model to evaluate restoration potential, which will allow decision makers to focus their efforts on the most promising sites. While the GIS is not required to characterize historical changes in the Willamette River floodplain, it was the most efficient method available.

ACKNOWLEDGEMENTS

This work was partially funded by the U. S. Environmental Protection Agency (EPA) and Oregon State University through the Pacific Northwest Research Consortium as part of cooperative agreement #CR824682. Although the research described in this paper has been funded (wholly or in part) by the EPA, it has not been subjected to the Agency's review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred. We are very grateful for the energetic work and scientific support of Bob Peak and Greg Bertrand at the ACOE district office in

Portland, Oregon, and Willa Nehlsen at the U. S. Fish and Wildlife Service. Without their incredible efforts to scan and digitize the historic flood and river maps, this project never would have gotten off the ground. Likewise, the dedication of John Christy, Ed Alverson, and Sue Kolar of the Oregon Natural Heritage Program and The Nature Conservancy were critical to the completion of this research.

REFERENCES

Allen C D 1994 Ecological perspective: linking ecology, GIS, and remote sensing to ecosystem management. In Sample V A (ed) *Remote sensing and GIS in ecosystem managment*. Covelo, Island Press: 111-139

Allen T H 1999 Areal distribution, change, and restoration potential of wetlands within the lower Columbia River riparian zone, 1948-1991. Corvallis, Oregon, Oregon State University Department of Geography, Ph D Thesis

Bayley P B 1995 Understanding large river-floodplain ecosystems. *BioScience* 45: 153-158

Benner P A, and Sedell J R 1997 Upper Willamette River landscape: a historic perspective. In Laenen A and Dunnette D A (eds) *River quality: dynamics and restoration*. Boca Raton, Lewis Publishers: 23-47

Boon P J, Calow P, and Petts G E 1992 *River Conservation and Management*. Chichester, John Wiley & Sons

Brookes A 1996 River channel change. In Petts G E and Calow P (eds) *River Flows and Channel Forms*. Oxford, Blackwell Science: 221-242

Christy J A, and Alverson E A In preparation Historic vegetation of Willamette Valley, Oregon, in 1850.

Decamps H, Fortune M, Gazelle F, and Pautou G 1988 Historical influence of man on the riparian dynamics of a fluvial landscape. *Landscape Ecology* 1: 163-173

Dixon M D, and Johnson W C 1999 Riparian vegetation along the middle Snake River, Idaho: zonation, geographical trends, and historical changes. *Great Basin Naturalist* 59: 18-34

Downward S R, Gurnell A M , and Brookes A 1994 A methodology for quantifying river channel planform change using GIS. In Kovar K (ed) *Variability in stream erosion and sediment transport*. Wallingford, IAHS: 449-456

Dykaar B B, and Wigington, P J 2000 Floodplain formation and cottonwood colonization patterns on the Willamette River, Oregon, USA. *Environmental Management* 25: 87-104

Frenkel R E, Gregory S V, and Sedell J R 1991 The Willamette River: An ecosystem in need of a new vision. Unpublished monograph

Gardiner, John L 1999 Willamette River floodplain restoration study: section 905(b) reconnaissance report. Portland, Oregon, Philip Williams & Associates, Report prepared for U S Army Corps of Engineers

Graf, W L 2001 Damage control: restoring the physical integrity of America's rivers. *Annals of the Association of American Geographers* 91: 1-27

Gregory S V 1999 Ecological, demographic, and economic evaluation of opportunities and constraints for riparian restoration. Unpublished monograph

Gregory S V, Hulse D W, Landers D H, and Whitelaw E 1998 Integration of biophysical and socioeconomic patterns in riparian restoration of large rivers. In Wheater H, and Kirby C (eds) Hydrology in a Changing Environment. Chichester, John Wiley and Sons.

Gregory S V, Landers D, Ashkenas L, Wildman R, Minear P, Oetter D, Bayley P, Andrus C, Pearson M, and Fernald S In review Historical and future trajectories of floodplains, forests, and off-channel habitats of the mainstem Willamette River. *Ecological Applications*

Gregory S V, Swanson F J, McKee W A, Cummins K W 1991 An ecosystem perspective of riparian zones. *BioScience* 41:540-551.

Gurnell A M 1997a Channel change on the River Dee meanders, 1946-1992, from the analysis of air photographs. *Regulated Rivers: Research & Management* 13: 13-26

Gurnell A M 1997b The hydrological and geomorphological significance of forested floodplains. *Global Ecology and Biogeography Letters* 6: 219-229

Gutowsky S L 2000 Riparian cover changes associated with flow regulation and bank stabilization along the Upper Willamette River in Oregon between 1939 and 1996. Corvallis, Oregon, Oregon State University Department of Geography, Master's Thesis

Harris R R, Hopkinson P, McCaffrey S, and Huntsinger L 1997 Comparison of a Geographical Information System versus manual techniques for land cover analysis in a riparian restoration project. *Journal of Soil and Water Conservation* 52: 112-117

Hulse D W, and Gregory S V 2001 Alternative futures as an integrative framework for riparian restoration of large rivers. In Dale, V H, and Haeuber, R A (eds) Applying Ecological Principles to Land Management, New York, Springer-Verlag

Hulse D, Gregory S, and Baker J (eds) 2002 *Willamette River Basin: A Planning Atlas.* Corvallis, Oregon, Oregon State University Press

Iverson L R and Risser P G 1987 Analyzing long-term changes in vegetation with geographic information system and remotely sensed data. *Advances in Space Research* 7: 183-194

Iverson L R, Szafoni D L, Baum S E, and Cook E A 2001 A riparian wildlife habitat evaluation scheme developed using GIS. *Environmental Management* 28: 639-654

Johnson W C, Dixon M D, Simons R, Jenson S, and Larson K 1995 Mapping the response of riparian vegetation to possible flow reductions in the Snake River, Idaho. *Geomorphology* 13: 159-173

Lam, A H S 1989 Geographic information systems for river corridor and wetland management. In Kusler J A and Daly S (eds) *Wetlands and River Corridor Management.* Berne, New York, Association of Wetland Managers: 404-407

Large A R G, and Petts G E 1996 Historical channel-floodplain dynamics along the River Trent: implications for river rehabilitation. *Applied Geography* 16: 191-209

Llewellyn D W, Shaffer G P, Craig N J, Creasman L, Pashley D, Swan M, and Brown C 1996 A decision-support system for prioritizing restoration sites on the Mississippi River alluvial plain. *Conservation Biology* 10: 1446-1455

Malanson G P 1993 *Riparian Landscapes.* New York, Cambridge University Press

Moser T J, Lindeman D R, Wigington P J, Schuft M J, and Van Sickle J In press Methods for multi-spatial scale characterization of riparian corridors. *Journal of the American Water Resources Association*

Mossa J and McLean M 1997 Channel planform and land cover changes on a mined river floodplain, Amite River, Louisiana, U. S A *Applied Geography* 17: 43-54

Mullane N 1997 The Willamette River of Oregon: a river restored? In Laenen A and Dunnette D A (eds) *River quality: dynamics and restoration.* Boca Raton, Lewis Publishers: 65-75

Muller E 1997 Mapping riparian vegetation along rivers: old concepts and new methods. *Aquatic Botany* 58: 411-437

Naiman R J, Décamps H, Pastor J, and Johnston C A 1988 The potential importance of boundaries to fluvial ecosystems. *Journal of the North American Benthological Society* 7: 289-306

Narumalani S, Zhou Y, and Jensen J R 1997 Application of remote sensing and geographic information systems to the delineation and analysis of riparian buffer zones. *Aquatic Botany* 58: 393-409

[NRC-CRAE] National Research Council Committee on Restoration of Aquatic Ecosystems- Science, Technology, and Public Policy 1992 *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy.* Washington, D. C., National Academy Press

Newson M D 1997 *Land, Water and Development: Sustainable Management of River Basin Systems*. London, Routledge

Petts G E and Calow P 1996 *River Flows and Channel Forms*. Oxford, Blackwell Science

Petts G E, Large A R G, Greenwood M T, and Bickerton M A 1992 Floodplain assessment for restoration and conservation: linking hydrogeomorphology and ecology. In Carling P A and Petts G E (eds) *Lowland Floodplain Rivers: Geomorphological Perspectives*. Chichester, John Wiley & Sons: 217-234

Russell G D, Hawkins C P, and O'Neill M P 1997 The role of GIS in selecting sites for riparian restoration based on hydrology and land use. *Restoration Ecology* 5: 56-68

Schiemer F, Baumgartner C, and Tockner K 1999 Restoration of floodplain rivers: the 'Danube Restoration Project'. *Regulated Rivers: Research & Management* 15: 231-244

Schulte L A and Mladenoff D J 2001 The original U S public land survey records: their use and limitations in reconstructing presettlement vegetation. *Journal of Forestry* 99: 5-10

Sedell J R and Froggatt J L 1984 Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U S A, from its floodplain by snagging and streamside forest removal. *Verh Internat Verein Limnol* 22: 1828-34

Sedell J R, Steedman R J, Regier H A, and Gregory S V 1991 Restoration of human impacted land-water ecotones. In Holland M M, Risser P G, and Naiman R J (eds) *Ecotones: The Role of Landscape Boundaries in the Management and Restoration of Changing Environments*. New York, Routledge, Chapman, and Hall: 110-129

Shankman D 1993 Channel migration and vegetation patterns in the Southeastern coastal plain. *Conservation Biology* 7: 176-183

Towle J C 1982 Changing geography of Willamette Valley woodlands. *Oregon Historical Quarterly* 83: 67-90

[ACOE] U S Army Corps of Engineers 1895 *Willamette River, Oregon, Portland to Eugene*. Map series

[ACOE] U S Army Corps of Engineers 1932 *Willamette River, Oregon, Portland to Eugene*. Map series

Ward J V, Tockner K, and Schiemer F 1999 Biodiversity of floodplain river ecosystems: ecotones and connectivity. *Regulated Rivers: Research & Management* 15: 125-139

White R 1995 *The Organic Machine*. New York, Hill and Wang

[WRI] Willamette Restoration Initiative 2001 *Restoring a river of life: the Willamette restoration strategy overview*. Salem, Oregon, Willamette Restoration Initiative

Willamette Riverkeeper 1996 *Riverlands Report*. Portland, Oregon, Willamette Riverkeeper

Winterbottom S J and Gilvear D J 2000 A GIS-based approach to mapping probablilities of river bank erosion: regulated River Tummel, Scotland. *Regulated Rivers: Research & Management* 16: 127-140

CHAPTER 3

LAND COVER MAPPING IN AN AGRICULTURAL SETTING USING MULTI-SEASONAL THEMATIC MAPPER DATA

Doug R. Oetter, Warren B. Cohen, Mercedes Berterretche,
Thomas K. Maiersperger, and Robert E. Kennedy.

Manuscript published in:

Remote Sensing of Environment
Elseveir Science Inc., New York, NY.
2001 - Vol. 76, Iss. 2, pp. 139-155.

ABSTRACT

To characterize agricultural and related land cover in the Willamette River Basin of western Oregon, we used a multi-seasonal Landsat TM data set consisting of five image dates from a single year. Georegistration among image dates was accomplished using an automated ground control point selection program. As radiometric normalization was critical to the success of the project, we devised a semi-automated approach based on the identification of no-change pixels in forest, urban, and water classes. For land cover ground reference we employed a variety of existing data sets, including low-level 35mm color slide photographs acquired by the USDA Farm Service Agency for crop compliance programs, 1:24000 color airphotos, and GIS coverages of county zoning and land use. Preliminary examinations of data structure included principal component analysis and plotting of training set temporal trajectories in spectral space with reference to existing crop calendars. A subsequent stratified, unsupervised classification algorithm, in combination with a geoclimatic ruleset and regression analysis, was used to label mapped cells. We created a map of 20 land cover classes, ranging from specific agricultural crops and urban building densities to forest age classes and orchards. An accuracy assessment indicated a final map error of only 26%. The map is now being used to model present and future landscapes for the basin.

KEYWORDS: Landsat Thematic Mapper, land cover mapping, crop cover mapping, Farm Service Agency, Tasseled Cap, Willamette Valley.

INTRODUCTION

The Pacific Northwest region of the United States has been a major focus for resource-related issues throughout the 1990s (FEMAT 1993, Tuchmann et al. 1996). Recent debates have centered around the effects of forest management on survival of late-successional forest dwelling species of plants and animals and on fish habitat. These and related topics were addressed in what is known as the President's Northwest Forest Plan (Tuchmann et al. 1996). In direct response to the Plan, the Pacific Northwest Ecosystem Management Research Consortium (PNW-ERC) was formed by the Environmental Protection Agency (EPA) in 1994. This group of agency and university scientists recognizes that the condition of Pacific Northwest ecosystems relies on effective management of not just the forested uplands of the region, but also of the human-populated valleys dominated by agricultural and urban environments. The PNW-ERC consists of 13 individual projects (Table 3.1) with the common research goal of understanding "...ecological consequences of possible societal decisions related to changes in human populations and ecosystems in the Pacific Northwest and [developing] transferable approaches and tools to support management of ecosystems at multiple spatial scales" (EPA 1997).

To meet its goal, the PNW-ERC required a land cover map of the Willamette River Basin (WRB) (Figure 3.1). The land cover map would be used both as a baseline for current ecological conditions and as a data source from which projections of alternative future landscapes would be developed. Each research project of the PNW-ERC required a fine-grained land cover map that could capture a wide variety of natural and anthropogenic environments, with detailed information about forest condition, agricultural practices, and urban development. The framework for the PNW-ERC research was based on a pilot study of the 23 km^2 Muddy Creek watershed in Benton County, Oregon (Hulse et al. 1999). That study identified 30 land use/land cover types using 1:24000 aerial photographs and ancillary information, and served as a potential model for the land cover map of the entire basin.

Table 3.1. Pacific Northwest Ecosystem Research Consortium (PNW-ERC) projects.

Project Title	Principal Investigator	Institutions	Spatial Extent	Topical Focus
Landscape patterns and processes	Stan Gregory	Oregon State University (OSU)	Basin	Landscape ecology
Historical changes in rivers, riparian forests, and terrestrial ecosystems	Stan Gregory	OSU	Valley floor	Geomorphology, vegetation change
Responses of aquatic vertebrates to large-scale environmental changes	Peter Bayley	OSU	Watersheds	Land cover, aquatic ecology, water use
Macroinvertebrate responses to anthropogenic landscape alterations in Willamette River Basin	Judith Li	OSU	Watersheds	Aquatic ecology
The historical, current, and projected future abundance, diversity, and distribution of terrestrial vertebrates in response to vegetation patterns, human impact, and land-use options	Jerry Wolff, Nathan Schumaker	OSU, Environmental Protection Agency (EPA)	Basin	Land cover, terrestrial ecology
Agricultural landscape impacts on ecosystem management in the Willamette Basin	John Bolte	OSU	Valley floor	Land cover, agriculture
Characterizing trajectories of demographic change: Past, present, and future population-landscape interactions in the Willamette River Basin	David Hulse	University of Oregon (UO)	Basin	Land cover, demography
Estimating the major economic costs, benefits, and externalities coming from and leading to changes in the management of ecosystem resources	Ed Whitelaw	UO	Basin	Land cover, forestry, water use, agriculture
Riparian influence on aquatic ecoystem nutrient and chemical status	Steve Griffith, Jim Wigington	Agricultural Research Service, EPA	Watershed	Land cover
The effect of riparian areas on the ecological condition of small perennial streams in agricultural landscapes of the Willamette Valley	Jim Wigington	EPA	Valley floor streams	Land cover, agriculture
Ecological functions of off-channel habitats, Willamette River, Oregon	Dixon Landers	EPA	Valley floor rivers	Riparian ecology, aquatic ecology
Evaluating landscape classifications for their utility in ecosystem management	John Van Sickle	Dynamac Corporation	Basin	Land cover
Development of fine-scaled vegetation cover and cover change data layers for the Willamette Basin	Warren Cohen, Doug Oetter	USDA Forest Service, OSU	Basin	Land cover

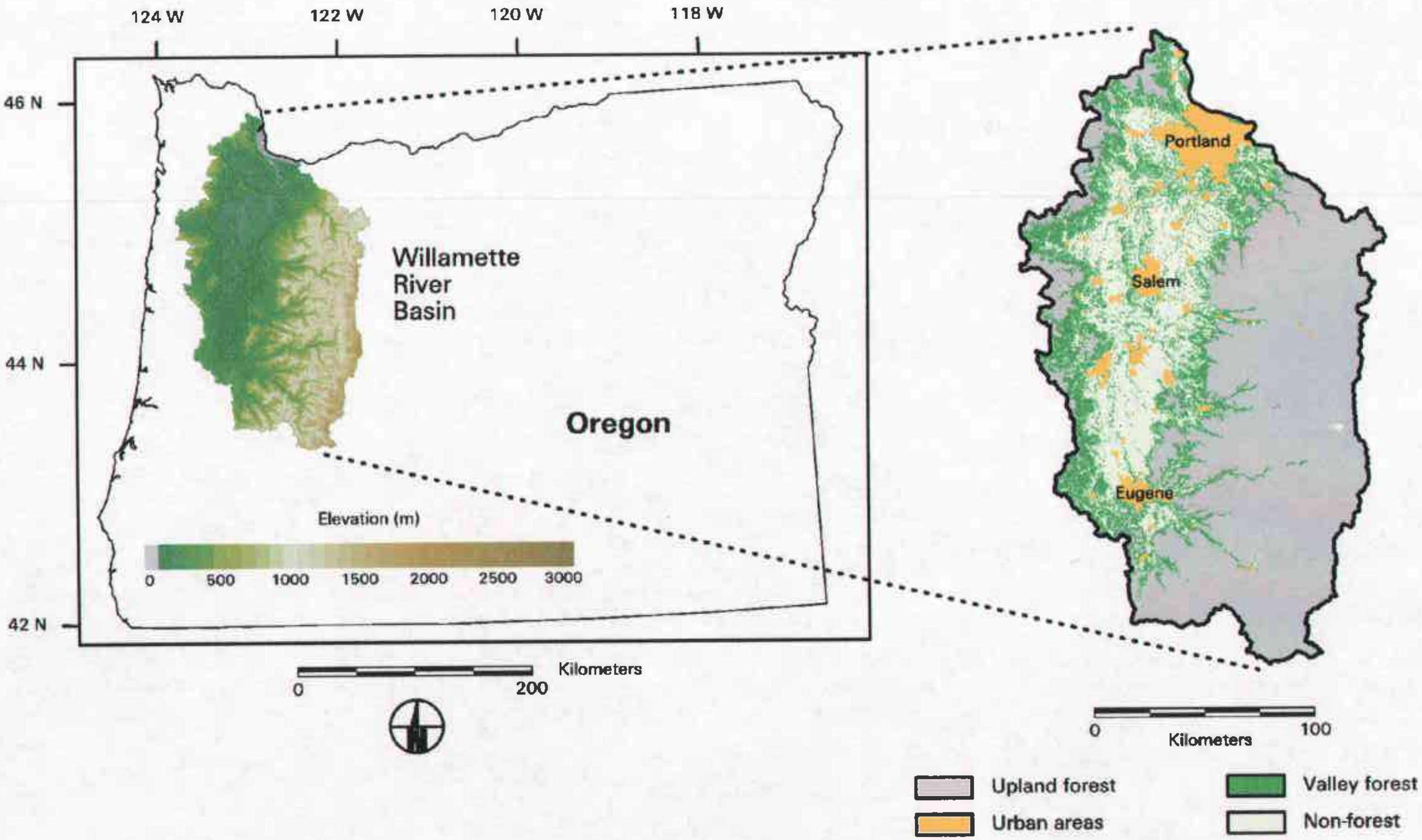

Figure 3.1. The Willamette River Basin in northwest Oregon. The Willamette River drains north from Eugene to Portland, where it joins with the Columbia River. Inset on left shows elevation. Blowup at right shows the basin divided into four units which define the steps used to complete mapping of the basin.

We referred to a large literature on the use of TM data for land cover mapping, especially for the broad land cover types that we were asked to identify: agricultural crops (Bauer et al. 1978, Buechel et al. 1989, Shueb and Atkins 1991), grasslands (Lauver and 1990). Our previous work had been focused on single-date TM data for forest cover mapping (Cohen et al. 1995, Cohen et al. 2001) and forest cover change detection using multi-year Whistler 1993), riparian areas (Hewitt 1990), and urban cover (Haack et al. 1987, Plunk et al. Landsat data (Cohen and Fiorella 1998, Cohen et al. 1998). In this study, we followed the lead of many other researchers who have recognized the benefits of using multi-seasonal imagery (within a given year) to map crops (Ryerson et al. 1985, Lo et al. 1986, Williams et al. 1987, Ehrlich et al. 1994, Brisco and Brown 1995, Pax-Lenney et al. 1996, Pax-Lenney and Woodcock 1997, Panigrahy and Sharma 1997, Brewster et al. 1999), grasslands (Henebry 1993), forests (Schriever and Congalton 1995, Wolter et al. 1995), and wetlands (Munro and Touron 1997, Lunetta and Balogh 1999). In addition, we elected to augment our remotely sensed data with ancillary geographic information systems (GIS) data (Zhuang et al. 1991, Adinarayana et al. 1994, Ehrlich et al. 1994, Carbone et al. 1996) and a digital elevation model (DEM) (Henebry 1993).

Since the upland forest portion of the WRB had previously been mapped (Cohen et al. 2001), our task was to map the valley floor, which we defined as a contiguous area ≤ 315 meters elevation. Our objectives for this project were to use multi-seasonal Landsat Thematic Mapper (TM) data (1) to produce a land cover map of the valley floor which would, to the extent possible, match a list of desired classes for agricultural, forest, natural, and urban cover types (Table 3.2), and (2) to extend our working knowledge of the Tasseled Cap transformation (Crist and Cicone 1984) into an agricultural setting. The resultant land cover map incorporates the advantages of multi-seasonal satellite imagery and GIS information to map detailed cover types across a broad spectrum, from forest and shrub land to crops and urban settings.

Table 3.2. Categorical list of the classes desired by the PNW-ERC.

1) Urban
    - a) Residential
        - i) 0-8 dwellings per acre
        - ii) 9-16 dwellings per acre
        - iii) >16 dwellings per acre
    - b) Commercial
    - c) Industrial
    - d) Open Space
    - e) Herbaceous-roads

2) Built (Non-Urban)
    - a) Commercial
    - b) RR2-5 Zoning
    - c) Within 2 acres of structures
    - d) Railroad
    - e) Roads
        - i) Primary roads
        - ii) Secondary highway
        - iii) Light duty road
        - iv) Unimproved road
    - f) Revetments

3) Hydro
    - a) Headwater streams
    - b) Open standing water
    - c) Streams > 1st order

4) Forested
    - a) 0-40 year old Douglas-fir
    - b) 41-120 year old Douglas-fir
    - c) 120 year old Douglas-fir
    - d) Mixed conifer / deciduous
    - e) Deciduous
    - f) Lower riparian forest

5) Agriculture
    - a) Grass seed / grain
    - b) Hybrid poplar
    - c) Nursery operations
    - d) Orchards
    - e) Pasture and haylands
    - f) Row crops
    - g) Vineyards, berries, and hops
    - h) Christmas trees
    - i) Mint
    - j) Meadowfoam
    - k) Confined animal operations
    - l) Farmsteads

6) Open / Woody
    - a) Shrub / brush
    - b) Fence rows
    - c) Oak savanna
    - d) Prairie (grass / forb)
    - e) Marsh (non-treed wetlands)

7) Percent Impervious surface
    - a) < 10%
    - b) 10-20%
    - c) > 20%

METHODS

Study area

The WRB occupies a 29,700 km^2 region in northwest Oregon bounded by the mountains of the Coast Ranges and the Cascade Range (Willamette Valley Livability Forum 1999). Over two million people, two-thirds of Oregon's population, inhabit the basin, primarily in the metropolitan areas of Portland, Eugene, and Salem. Although the basin contains only 12% of the State's land area, it accounts for over 50% of its $3.5 billion agricultural economy (ODA 1999). In addition, the basin supports a thriving forest products industry, primarily due to the presence of highly productive Douglas-fir forests. Oregon exported over $1.2 billion in wood products in 1997, much of it from the intensively logged WRB (Willamette Valley Livability Forum 1999). The WRB consists of three physiographic provinces: the Coast Ranges, Willamette Valley, and Western Cascades (Franklin and Dyrness 1988). The Coast Ranges are mountains composed of volcanic and sedimentary rocks that were accreted to the continent from the ocean floor to the west. The dominant natural vegetation of the Coast Ranges includes western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menziesii*); much of the area is intensively managed in Douglas-fir plantations. The volcanic Western Cascades montane province is vegetated predominantly by mixed conifer forests, especially Douglas-fir and western hemlock. Both provinces have substantial bigleaf maple (*Acer macrophyllum*) and red alder (*Alnus rubus*) hardwood stands in disturbed areas. The Willamette Valley contains alluvial terraces and floodplains deposited during Miocene glacial floods, interrupted by rolling hills of volcanic and sedimentary origin. The pre-settlement vegetation of this area (Johannsen et al. 1970, Towle 1982, Christy 1999) most likely resembled predominant present-day natural vegetation (where it exists): riparian hardwood forests and swamps, wet and dry prairie grasslands, herbaceous transition areas, Oregon white oak (*Quercus garryana*) woodlands, and mixed conifer remnant forests (Franklin and Dyrness 1988).

The WRB has a cool Mediterranean climate, with mild, wet winters and cool, dry summers (Jackson and Kimerling 1993). The valley floor receives about 100-125 cm of precipitation in an average year, while the Coast Ranges and the Cascades get much more, due to orographic lifting of the prevailing westerly winds off the Pacific Ocean. The mountains may get up to 300 cm of precipitation in an average year, much of it in snowpack from October through June. Average temperatures on the valley floor range from a mean January minimum of 1°C to a mean July maximum of 30°C (Oregon Climate Service 1999). Elevation in the basin varies from 15 m above sea level at the confluence of the Willamette River and the Columbia River to 3200 m at the top of Mount Jefferson (Willamette Valley Livability Forum 1999).

While timber extraction is the main industry in the upland forests of the basin, agriculture dominates the valley floor. Because of the rich alluvial soils and the temperate climate, the Willamette Valley supports over 120 different crops (ODA 1999). Depending on soil type and location, commodities range from exotic fruits and vegetables to a variety of grains and nuts. The leading products include nursery and greenhouse stock, seed crops, Christmas trees, fruit and nut crops, and peppermint (ODA 1999).

The spatial and temporal pattern of agriculture in the valley is quite diverse, with some crops, such as grass seed in the south, occupying very large and semi-permanent plots, whereas in the north, smaller, more concentrated plots produce a wide variety of specialty crops such as asparagus, blueberries, and kiwifruit (Daryl Ehrensing, personal communication) (Figure 3.2). Management of the valley hills also creates a dynamic picture, as Christmas tree farms blend with Douglas-fir plantations in an intensively cultivated setting. Adding complexity to the landscape is the population growth of the basin and the steady sprawl of urbanization into agricultural and forest areas (Willamette Valley Livability Forum 1999).

Remotely sensed imagery and preprocessing

To construct the land cover map of the Willamette Valley floor using TM data, multiple rows (28-30) in path 46 were required. We selected 1992 because ground and airphoto reference data from 1992 and 1993 were available. Moreover, that was a dry year in the valley, and five nearly cloud-free TM image data sets from one growing season were available. The dates of the TM images were March 19, May 6, June 7, July 25, and August 26 (Figure 3.3); each date of imagery covered three consecutive rows from the same path, to capture the entire study area. As such, the three rows of imagery for each date could be treated as a single spectral data set for processing purposes. These five dates represent the near full progression of phenological development of the major crops grown in the valley, which is critical for the accurate classification of agricultural land cover types (Pax-Lenney and Woodcock 1997). Missing are images from just before greenup (e.g., before March) and just after harvest of late-season crops (e.g., mid- to late-September). Each image had excellent quality, and only the June image contained clouds, confined to small areas in the northwest corner of the scene.

Because we intended to analyze changes in Tasseled Cap vegetation indices among the five different images to identify land cover types, georegistration and radiometric normalization of the images were important preprocessing steps. We purchased the images from the USGS EROS Data Center with systematic correction. Georegistration was done in two steps. First, we registered the four other images to the June 7 image using an affine transformation. Second, all five images were resampled to match a geocoded TM base image mosaic from 1988 (see Cohen et al. 2001), using a second-order polynomial nearest-neighbor transformation. To select the points used to build the transformation matrix (tie points), we employed a program developed by Kennedy and Cohen (In press). The procedure locates tie points by maximizing an index of normalized cross-correlation for small subsets of the two images to be matched. Required user input is minimal: pixel size, relative rotation of the images, selection of an initialization point in both images, and the desired density of the output grid of tie points. The program selected over 150 points for each image to provide a

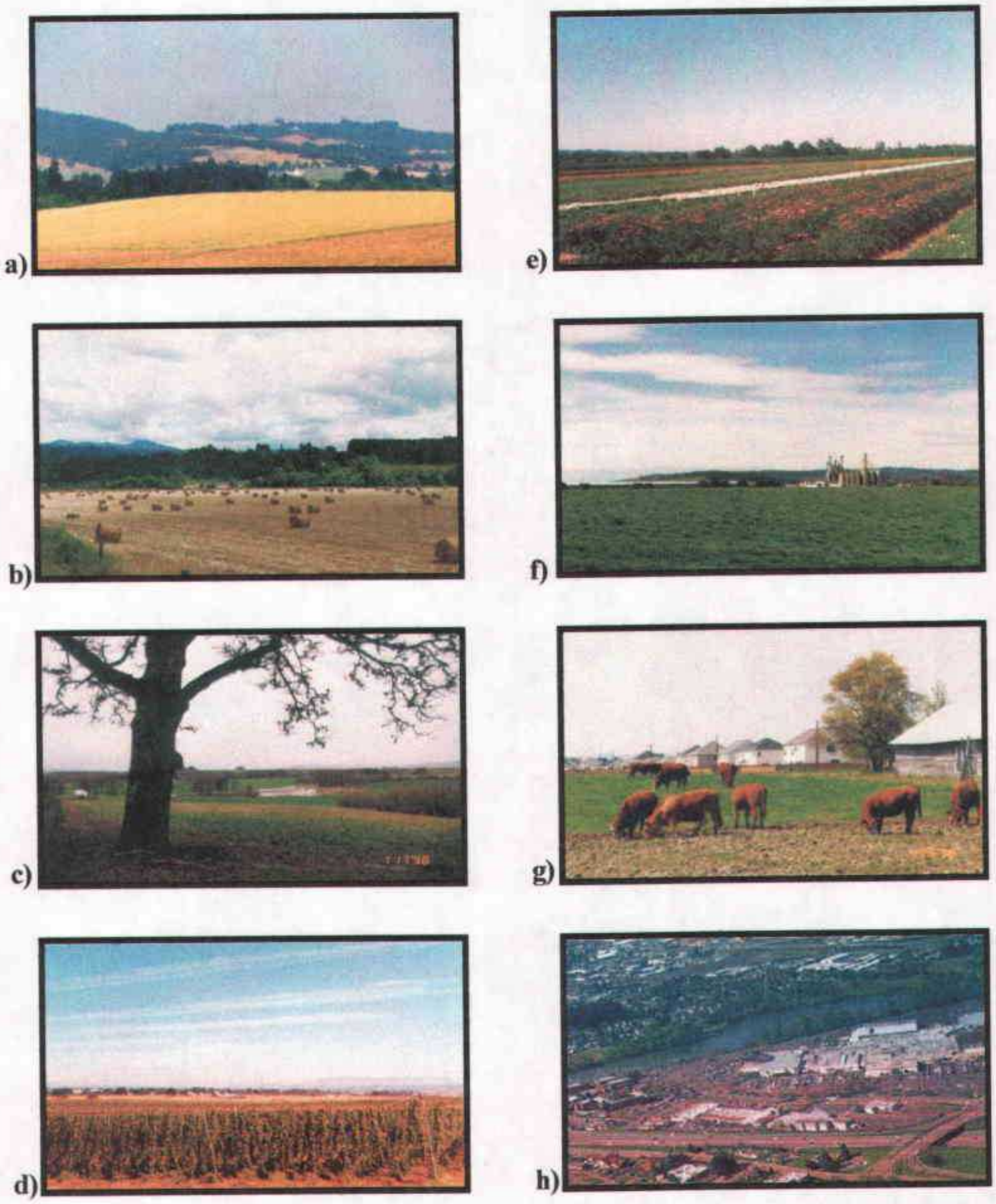

Figure 3.2. Photographs that exemplify Willamette Valley landscapes (photos courtesy of Tom Moser): a) the bright yellow radish seed crop in the foreground stands out against the hills behind; b) hayfields typically occupy the vales, ringed by forest stands above; c) the Willamette Valley contains many dense riparian galleries of hardwoods; d) extensive fields of hops; e) the valley's cool dry summers aid several large nursery and container crop operations; f) the poorly-drained southern portion of the valley produces most of the nation's rye grass seed; g) farms and fields are giving way to suburban expansion throughout the valley; h) Valley River mall in Eugene represents a high-density built environment found in the more populous urban areas.

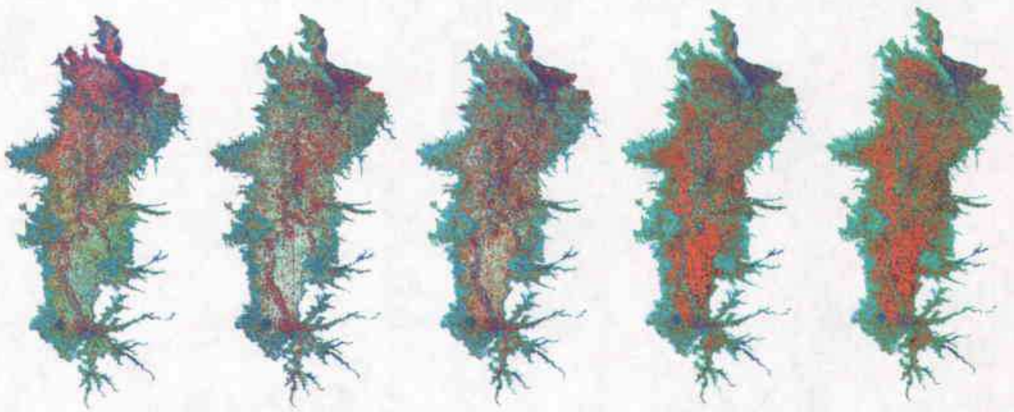

Figure 3.3. Landsat Thematic Mapper images acquired in 1992. Each image is a multiple scene combination of rows 28, 29, and 30 from path 46, shown in the Tasseled Cap transformation (brightness, greenness, and wetness in red, green, and blue, respectively).

second-order polynomial transformation with less than one-half pixel root mean square error.

Our radiometric normalization procedure was based on the approach of defining radiometric control sets along a brightness gradient from very dark (e.g., water and forest) to very bright (e.g., urban development) using co-locatable pixels. Rather than selecting co-located control sets manually in both the "subject" and "reference" images (e.g., Volgelmann 1988, Eckhardt and Verdin 1990), we elected to use "difference-image" space to capture the control set of no-change pixels. For each of the four subject images, we created a difference image (Coppin and Bauer 1996) by subtracting the subject image from the June 7 reference image for each of the six TM reflectance bands. We then added band 4 from the June 7 image as a baseline against which spectral differences could be contrasted (see Cohen and Fiorella 1998). Each of these 7-band images was individually subjected to iterative clustering to define an optimal control set of no-change pixels, which were selected both by visual inspection of the image and histogram analysis. The addition of band 4 from the reference image helped ensure that pixels along the full brightness gradient (water, forest, and urban conditions) were selected as candidate control sets. Subsequent iterations of clustering successively eliminated questionable control set pixels until an optimum set was retained. The pixels kept as the no-change control set were then subsampled to produce 666 pixels for each of the water, forest, and urban classes, for a total of 1998 pixels for each subject image. Sorted geographically, half of these pixels were used to develop univariate regression models relating the subject DN to the reference DN for each band; the other 999 pixels were withheld for testing of the normalization models.

Preliminary examination of the data set revealed a wide range of spectral contrasts among land cover types and a generally consistent signature pattern within individual agricultural fields. To reduce the data set size, we elected to use the first three components of the Tasseled Cap transformation (Crist and Cicone 1984) for further analysis. Previous experience mapping forests in western Oregon demonstrated a great utility in the physical interpretation of the brightness, greenness, and wetness indices for the interpretation of natural conditions (Cohen and Spies 1992, Cohen et al. 1995, Cohen et al. 1998). The needs of this project afforded us our first opportunity to extend our knowledge of these indices into the agricultural land cover system for which the transformation was originally designed (Kauth and Thomas 1976).

Ground and airphoto reference data

Our mapping approach in this project involved stratifying the WRB into four broad cover types: upland forest, urban areas, valley forest, and valley non-forest (agricultural, natural, and built) (Figure 3.1). The land cover mapping of the upland forest (defined by a boundary based on the 315 m contour) had already been completed as part of a separate project covering Oregon forests west of the Cascade Range crest (Cohen et al. 2001). The products from that effort were continuous predictions for percent green vegetation cover, percent conifer cover, and closed conifer stand age, derived from single-date 1988 TM imagery. With those data layers in hand, our work for this project focused on the other three broad cover types of the basin.

For the urban areas, we obtained six 260 ha 1997 color digital orthophotographs (DOPs) (Table 3.3) at 1.2 m pixel resolution from Metro (http://www.metro.dst.or.us), the Portland-area regional government. These photos were used to reference an initial classification of land cover types within the urban areas.

To reference the valley forest, we used 1993 color photographs at 1:24000 scale acquired from WAC Corporation (http://www.waccorp.com/), a local airphoto company (Table 3.3). These airphotos were from the same source used to create the land cover map for the Muddy Creek pilot project (Hulse et al. 1999). We obtained access to a geographically distributed collection that covered almost half the valley floor. For 235 forested plots located on the photos, averaging 2 ha in size, we collected estimates of percent cover of conifer, broadleaf, shrub, open, and shadow (Table 3.3, Figure 3.4). Half of these plots were used for training, and the rest were left for testing. In addition to forest, we identified 43 plots of semi-permanent non-forest (filbert orchards, vineyards, and tree crops such as hybrid poplar and Christmas trees) with this photo set.

These two photo sets were adequate for the relatively stable land cover types, but for most agricultural and non-forest classes we were more concerned that annual variation in cropping patterns could render data from any year other than 1992 useless. Thus, the primary reference data set we used came from 1992 Farm Service Agency (FSA) (http://www.fsa.usda.gov/EDSO/or/or.htm) 35mm color slide photographs (Table 3.3). Each year, local FSA offices contract aerial photography missions to provide documentation of county-wide crop conditions for the FSA staff to certify farmer's crop reports (Buechel et al. 1989). The FSA agents typically view the photographs, which are acquired in late May or early June, and compare their interpretations with the farm report. The slides are acquired using standard hand-held 35 mm cameras without telephoto lenses, usually from a flying height of around 1.5 km. This provides a color image of the land surface that is roughly three by two kilometers in size. As these slides were quite inexpensive ($10 for the first slide and $1 for each additional slide), we purchased 369 slides, covering 33 separate focus areas, from seven different FSA offices. The focus areas were chosen both to match the existing 1993

Table 3.3. Ground reference data.

Source	Scale/ Resolution	Date	Used for	Training Plots	Testing Plots	Total
WAC airphotos	1:24000	1993	Valley forest	119	116	235
			Non-forest	20	23	43
FSA slides	≈1:1500	1992	Verification	153		153
			Non-forest	406	553	959
			Urban		23	23
Metro digital orthophotographs[1]	1.2 m	1996	Urban	-	-	-
Moser landscape photos[1]	n/a	1994-1998	Non-forest	-	-	-
Total				698	715	1413

1- These data sets were not used to develop training and testing plots, but for visual reference and as interpretation aid.

WAC airphoto coverage and to represent the full diversity of land cover types in each county, using the expert knowledge of the FSA agents as a guide. Each slide was scanned into a Tag Image File (.tif) at 300 dpi using a Polaroid Sprintscan 35/ES slide scanner and then georeferenced to the TM imagery using a minimum of nine ground control points for a root mean square (RMS) error of under 10 m. To use the slides, we projected them on a white wall above our workstation while displaying the digital mosaic of the scanned and rectified version on the computer monitor. The detail of the projected image (about 1:1500) allowed a substantial amount of interpretable detail, with individual trees, houses, roadways, even plowing patterns and irrigation marks easily discernible.To train our interpretation of crop types from the slides, we interviewed several of the FSA agents on their identification techniques. As they related, the color and texture of fields reveal clues as to the crop types (Goodman 1964). Most of the field crops, especially grass seed and winter wheat, are at peak growth when the slides are acquired in late spring. At that time, the row crops, which are planted later and depend on irrigation through the summer, have barely broken soil and will frequently have visual evidence of irrigation. Other land cover types, such as improved pasture and hayfields, can be denoted by animal paths or the accumulation of hay bales. We used what we learned from FSA agents to photo-interpret land cover for 501 fields in five of the 33 geographically separated focus areas (Figure 3.4), and then compared our interpretations with the actual crop reports filed on those fields by the farmers, using a Freedom of Information Act request. Only 153 of the 501 fields were included in the crop reporting system for that year (Table 3.3). We used the knowledge gained from the crop reports to develop an interpretation technique which employed 59 separate land cover codes (Table 3.4) based on visual interpretation of the FSA slides. In some cases, the land cover code depended on when the field greened-up or went into senescence, which we inferred from inspection of the five dates of TM imagery. The information obtained from the farmer's crop reports helped us identify several spectrally unique crops, such as radish seed, sugar beet seed, and mint. We also created land cover codes for non-agricultural land cover, including rural residential buildings, other urban, wetlands, natural prairies, natural shrub, and oak savanna. Most of these codes were based on our inspection and knowledge of the landscape, without the benefit of verification from the crop reports. Following the verification stage, we then photo-interpreted land cover for an additional 634 plots in the remaining 28 focus areas for a total of 1135 FSA plots for training and testing. Plots within each focus area were chosen to represent the full diversity of land cover types within the area; therefore the frequency distribution of reference plots (Table 3.4) reflects the relative abundance of cover types in the valley. All of the 153 verification plots were used for training the image classification.

In addition to the photographic data sets, we used some additional information for reference. The most valuable of these was a GIS coverage provided by a colleague (Tom Moser, personal communication) which located 452 global positioning satellite-determined points in conjunction with a photographic collection of over 500 oblique color photographs of the valley, showing crop types, natural conditions, structures, etc. While these photographs were taken over several years of field reconnaissance after 1992, they were still useful for cross-checking our interpretation of the FSA slides and

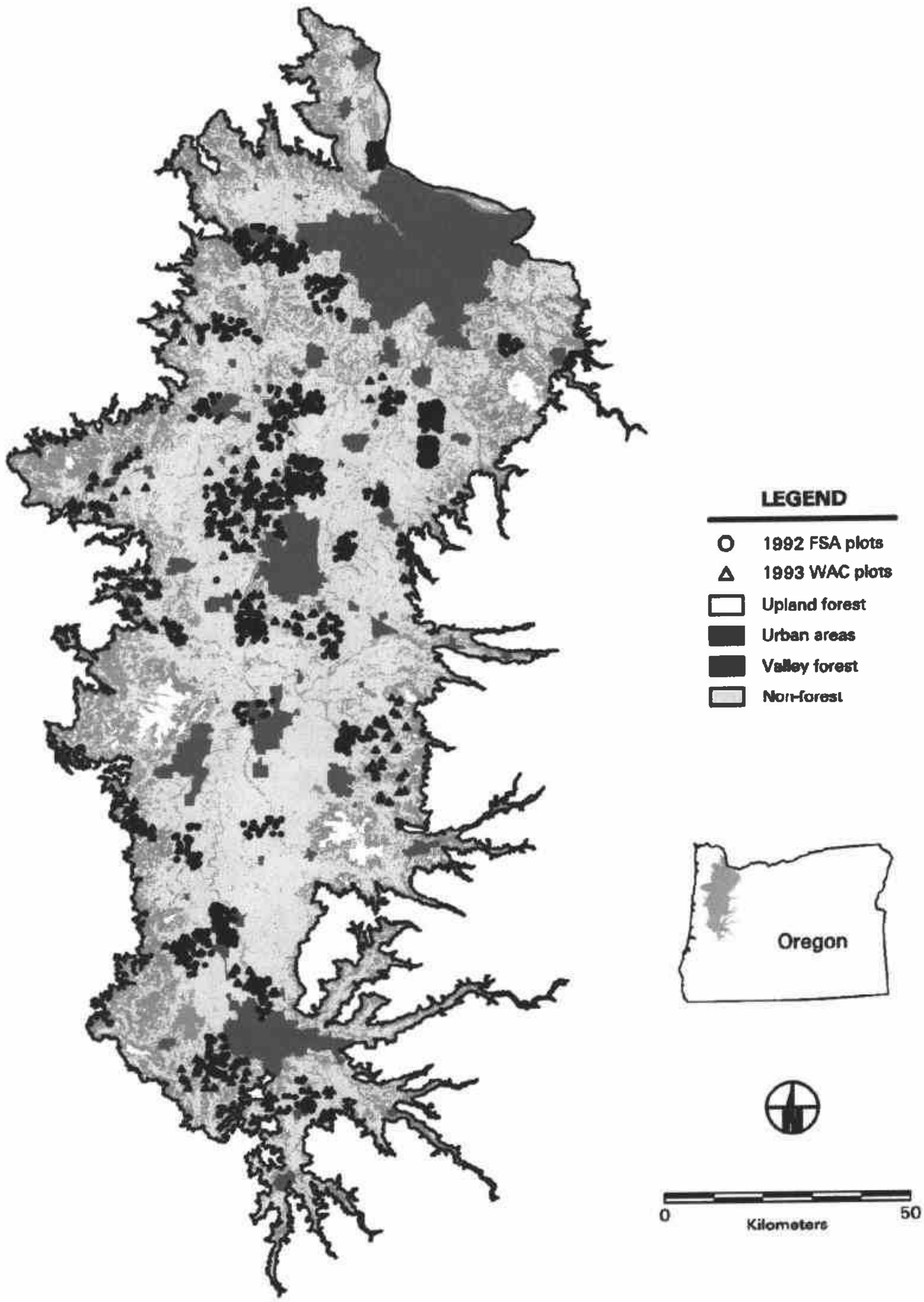

Figure 3.4. Ground reference points (training and testing) for forest and non-forest sites within Willamette Valley, shown over the four mapping units.

Table 3.4. FSA crop interpretation codes for non-forest.

Interpretation code	n(t)[1]	n(v)[2]	FSA crop report	Typical cover type	Final map class
B	25			Bare (fallow, clearcut, rock)	Bare/fallow
BER	14	1	Red raspberries	Berries, caneberries	Pasture/natural
BG	16			Burned grass	Field crop
BG2	7			"	Field crop
BLT	14			Built or other industrial use	Built high density
CC	5			Clearcut during the year	Bare/fallow
CG	2			Cleared grass	Field crop
CO	1	1	Fir trees	Conifer seed orchard	Forest closed conifer
DC	4			Double cropping w/ irrigation	Row crop
DC2	8			"	Row crop
DC3	7			"	Row crop
DC4	1			"	Row crop
DC5	3			"	Row crop
DC6	1			"	Row crop
ERC	5	1	Silage corn	Early row crop (silage corn)	Row crop
F	18	5	Fallow	Fallow	Bare/fallow
FC	118	33	Fescue	Field crop (barley, fescue, oats, strawberries, wheat)	Field crop
FC2	6	2	Clover	Cover crop	Field crop
FO	16			Farm operation: barns, coops, etc…	Built low density
G	43	32	Annual rye, perennial rye, orchard grass, fescue	Grass field	Field crop
H	41			Hops	Hops
HY	19	3	Hayfield	Hayfields	Pasture/natural
IFC	18	5	Irrigated alfalfa, hay	Irrigated field crop (hayfield, alfalfa, mint)	Field crop
IFC2	9			"	Field crop
IN	7			Inactive agricultural land	Pasture/natural
IP	58	7	Improved pasture	Improved pasture	Field crop
LFC	14	1	Sudan grass	Late field crop (alfalfa, spring plantings, clover, radish)	Field crop
LFC2	20	1	Barley	"	Field crop
LFC3	2	1	Strawberries	"	Field crop
LFC4	4			"	Field crop
LFC5	1	2	Red clover seed	Clover seed	Field crop
M	23	3	Mint	Mint	Mint
MA	15			Marsh and flooded field crops	Flooded/marsh
N	-			Nursery	Not used
O	53	8	Filberts	Orchard	Orchard
P	43	15	Pasture	Pasture	Pasture/natural
PK	6			Park or golf course	Park
POP	3			Poplar for pulpwood	Forest closed hardwood
PRA	17			Natural grasslands & prairies	Pasture/natural
Q	4			Quarry	Bare/fallow
R	8	4	Radish seed	Radish seed	Row crop
RC	87	16	Field corn	Row crop (field corn, sweet corn, squash, peas, green beans)	Row crop
RC2	5	3		Sweet corn	Row crop
RC3	5	4		Sweet corn	Row crop
RC4	9	2	Green beans	Row crop (field corn, sweet corn, squash, peas, green beans)	Row crop

Table 3.4 (continued). FSA crop interpretation codes for non-forest.

Interp. code	n(t)1	n(v)2	FSA crop report	Typical cover type	Final map class
RC5	19			"	Row crop
RR	7			Rural residential	Built low density
SAV	15			Oak savanna	Pasture/natural
SB	18	1	Sugar beet seed	Sugar beet seed	Row crop
SC	2			Scotch broom	Pasture/natural
SH	45			Shrub and brush land	Pasture/natural
UHD	6			Urban built high-density	Built high-density
ULD	10			Urban built low-density	Built low-density
UMD	7			Urban built medium-density	Built medium-density
V	12			Vineyard	Row crop
W	5			Water	Water
X	35	2	Christmas trees	Christmas trees	Pasture/natural
YO	8			Young filbert orchard	Orchard
YX	8			Young Christmas trees	Pasture/natural
Total	**982**	**153**			

1- Number of plots used for training and testing of classification algorithms.
2- Number of plots used for verification of FSA slide interpretation.

for identifying general cropping patterns. They were not used explicitly for training or testing classification algorithms.

Image analysis

The image processing steps used to construct the WRB land cover map were specifically designed for each of the three broad cover types in this study: urban, valley forest, and non-forest (Figure 3.5). The overall process was hierarchical (Lauver and Whistler 1993, Ehrlich et al. 1994, Pax-Lenney et al. 1996).

After eliminating the upland forest from consideration, the first step in mapping the Willamette Valley involved stratifying the pixels contained within Oregon's urban growth boundary zoning areas. Each of the 89 urban areas in the WRB (Figure 3.1) has an identified boundary within which the city must attempt to restrict development in accordance with its comprehensive land use plan, as required by the Oregon statewide land use law (http://www.lcd.state.or.us/issues/issues.htm). Our goal in classifying the urban stratum was to identify several land cover types that could be combined with census data to indicate land use and population density. Unsupervised classification of the 15-band, 5-date Tasseled Cap data set, using the Metro DOPs as reference, was used to separate urban areas into three desired classes (high-density built, medium-density built, and water), and a confused class (urban other), which was reclustered in later steps.

For the second step, all the pixels outside the urban areas were assessed to distinguish forest versus non-forest, and if forest to further classify forest characteristics (Figure 3.5). The separation of forest and non-forest was an important procedure, both for management implications and image processing decisions. We used the training plots developed from the 1993 color photographs to label unsupervised clusters derived from the 15-band Tasseled Cap data. Our labeling of clusters as forest was conservative, since the rejected classes would be subjected to further scrutiny in the third classification stage, and could thus be reincorporated as forest in a later step. Pixels labeled as closed forest (defined as ≥ 70% forest cover), were separated into closed conifer, closed mixed, and closed hardwood classes with a supervised classification (Schriever and Congalton 1995), defined respectively as 0-30%, 31-69%, or 70-100% of the total forest cover in hardwood. We tried to divide the closed hardwood class into oak and non-oak classes, but were unable to do so with adequate confidence; however, an orchard class was identified and retained. Closed conifer pixels were then reclassified into three age categories by applying multiple regression stand age models developed for the upland forest (Cohen et al. 2001) to the 1988 TM imagery for which they were developed.

The third step involved classification of all remaining pixels, including the urban other class from the first step and the pixels rejected as closed forest from the second step (Figure 3.5). We had some confidence in the spectral separability of tentative class groups based on preliminary graphs of the training clusters (Figure 3.6). The temporal signatures of the agricultural cover types (Lo et al. 1986, Williams et al. 1987), especially the Tasseled Cap greenness component, resembled a Willamette Valley cropping calendar (ODA 1999). Using a 16-band image created by adding a digital elevation model (DEM) to the 15-band Tasseled Cap spectral data set, we conducted a maximum likelihood supervised classification to produce 10 major classes (tree crop, row crops, field crops, pasture, natural, bare, built, seasonally flooded, irrigated, and water). We separated the major groups into subclasses where further divisions were statistically justifiable (San Miguel-Ayanz and Biging 1997).

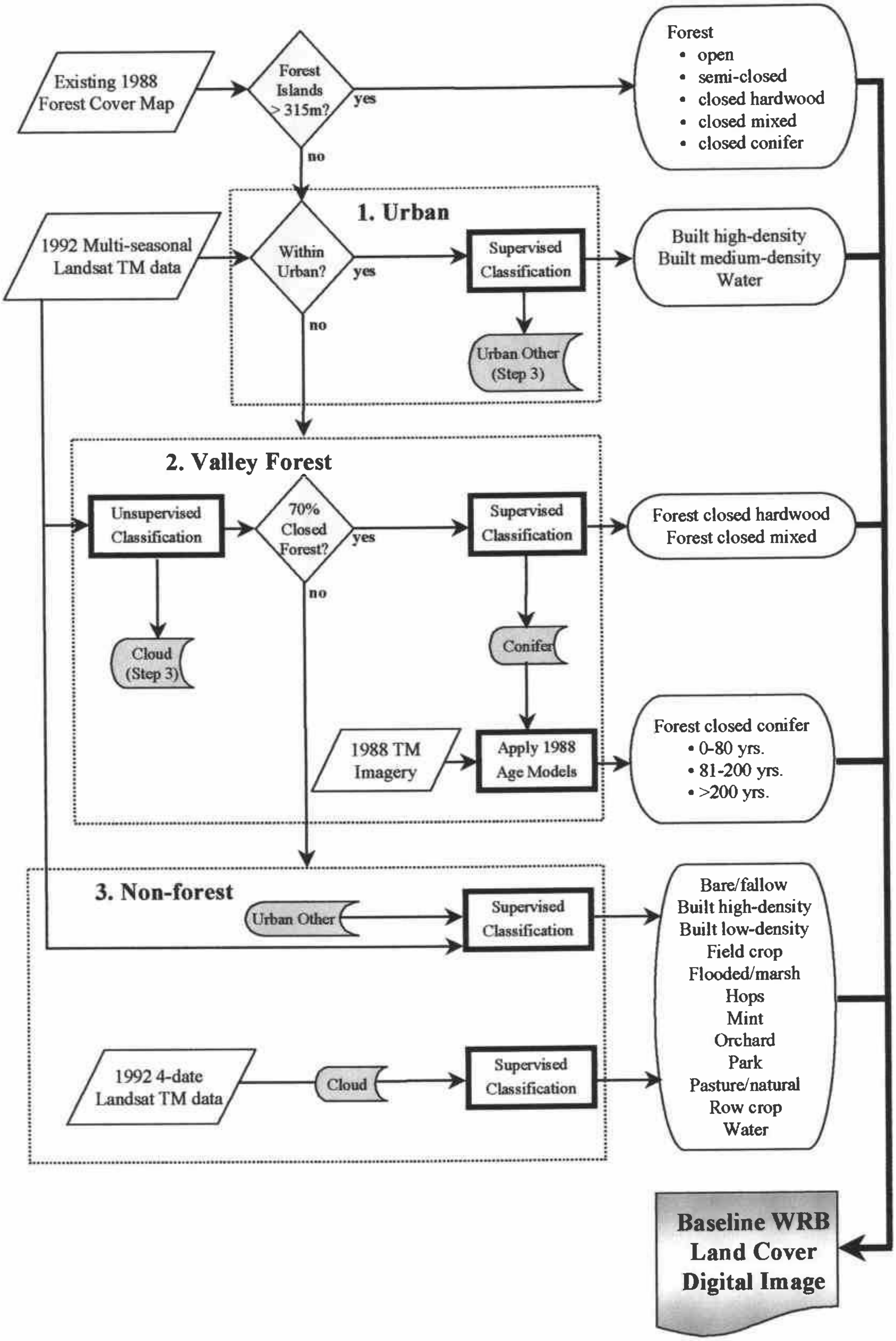

Figure 3.5. Flow chart of the image processing steps.

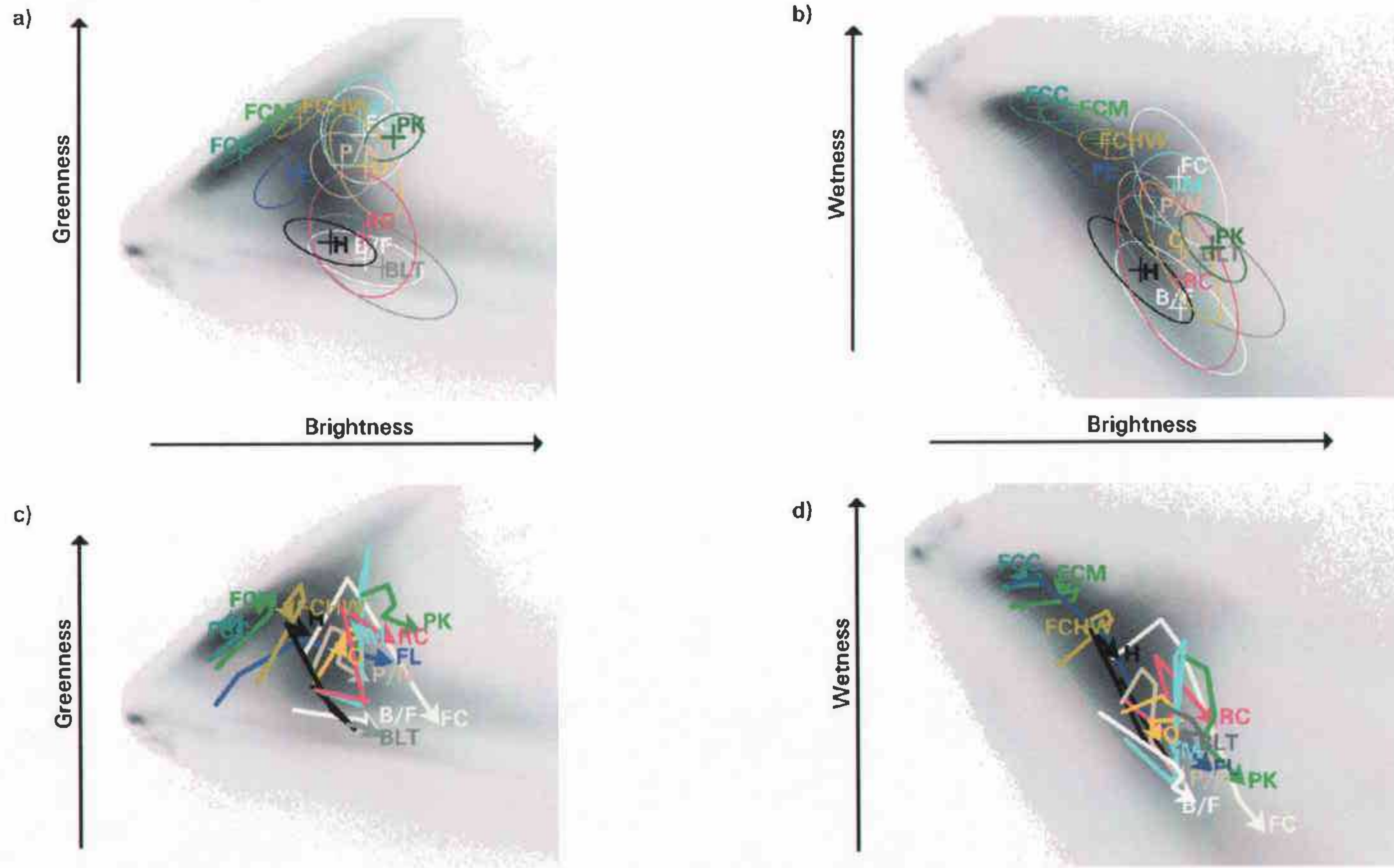

Figure 3.6. a) and b): Spectral signature means with ellipses drawn at one standard deviation for training plots in a) brightness-greenness and b) brightness-wetness feature spaces for thirteen valley land cover types for the 7 June image. c) and d): Spectral signature mean trajectories for the same training plots for the five dates in c) brightness-greenness and d) bightness-wetness feature space. The arrows for each land cover type show the change in the mean values of the training plots from March through August. See Table 3.8 for code definitions.

One final clustering was performed to reclassify pixels that were obscured by clouds in the June 7 image (Figure 3.5). This was done with a supervised classification of a 13-band (four-date plus DEM) image to cluster those pixels into the final classes using similar decision rules as above.

Map generation and error characterization

For the generation of our final map, we combined the output classes from the three stages of image processing to produce 20 distinct classes. The accuracy of the entire map was assessed by constructing an error matrix using 715 testing plots, divided among valley forest, non-forest, and urban (Table 3.3). Assessment of the closed forest conifer age classes was done separately, using ground reference data for 71 plots in the upland forest area (Cohen et al. 2001). For the land cover class accuracy assessment, we employed a mode-decision rule for each plot determination (i.e., the predicted value of a plot was set to the class which had the highest number of pixels within that plot; there were no ties).

RESULTS

Radiometric normalization

Radiometric normalization was accomplished by applying the regression equations in Table 3.5 to each band of the four subject images. Half of the control set pixels were used to develop the regression models and the other half were used to test the models. Coefficients of determination for the models ranged from 0.78-0.99. Slopes and offsets varied from 0.83 to 1.64 and from –21 to 16, respectively. The testing half of the control set was used to determine the efficacy of the normalization equations. For each image and every band, the slope of the line between the normalized

Table 3.5. Radiometric normalization models. The band normalization equations calculate the normalized band value (b*x*n) as a function of the raw value (b*x*) (where *x* is the band number). Model R^2 was calculated for the training pixels, while Testing R^2 was calculated on an independent testing set. The Testing Slope and Testing Intercept refer to the regression line of predicted versus observed values for the testing set. Testing Slopes close to 1 and Testing Intercepts close to 0 are considered ideal.

Image date	Band normalization equations	Model R^2	Testing R^2	Testing Slope	Testing Intercept
March 19	b1n = 1.436 * b1 - 20.535	0.889	0.896	1.02	-1.47
	b2n = 1.463 * b2 - 6.449	0.887	0.894	1.01	-0.31
	b3n = 1.635 * b3 - 11.869	0.919	0.924	1.01	-0.23
	b4n = 1.449 * b4 - 3.738	0.922	0.920	0.99	0.46
	b5n = 1.412 * b5 - 0.661	0.933	0.933	1.00	0.30
	b7n = 1.567 * b7 - 0.911	0.931	0.935	1.02	-0.14
May 6	b1n = 1.151 * b1 - 9.082	0.964	0.955	0.98	2.15
	b2n = 1.136 * b2 - 2.215	0.968	0.956	0.98	1.27
	b3n = 1.193 * b3 - 2.615	0.972	0.965	1.00	0.46
	b4n = 1.059 * b4 + 0.697	0.955	0.949	0.99	0.91
	b5n = 1.117 * b5 - 0.655	0.987	0.984	1.00	0.60
	b7n = 1.121 * b7 + 0.320	0.975	0.975	0.99	0.73
July 25	b1n = 0.832 * b1 + 16.497	0.897	0.892	1.00	-0.13
	b2n = 0.853 * b2 + 6.057	0.822	0.816	0.96	1.00
	b3n = 0.844 * b3 + 6.100	0.824	0.805	0.93	1.57
	b4n = 1.011 * b4 + 4.597	0.945	0.941	1.01	-0.28
	b5n = 1.037 * b5 + 2.750	0.936	0.914	0.99	0.09
	b7n = 0.976 * b7 + 1.423	0.846	0.829	1.00	-0.17
August 26	b1n = 1.114 * b1 + 7.161	0.913	0.902	0.99	0.67
	b2n = 1.056 * b2 + 5.376	0.788	0.772	1.03	-0.67
	b3n = 1.017 * b3 + 7.049	0.777	0.684	0.93	1.69
	b4n = 1.139 * b4 + 8.358	0.969	0.966	1.00	0.13
	b5n = 1.178 * b5 + 2.639	0.955	0.949	0.98	0.76
	b7n = 1.206 * b7 + 2.070	0.895	0.886	1.00	0.16

subject and reference pixels was close to 1 and the intercept is close to 0, indicating that the regression equations were effective at normalizing the imagery.

FSA slide interpretation

As we were previously inexperienced with photointerpretation of agricultural land cover types, especially from FSA color slides, we sought to confirm our initial interpretation within five of the 33 study sites. For 153 plots, the actual crops grown in the study year, as reported by the farmers, were translated into our interpretation codes. Only 18 plots were interpreted incorrectly, for an overall photo interpretation error of 12 % (Table 3.6).

Classification

We defined our study portion of the WRB using an outer perimeter based on the 315 m contour line, which is consistent with the valley ecoregion definition (Ormernik 1987, Franklin and Dyrness 1988). This 13,826 km^2 area was divided into four mapping stages. While most of the upland forest was intentionally excluded from this study as it was already mapped (Cohen et al. 2001), several small islands of land (totaling 257 km^2) above 315 m elevation were contained within the study boundary. These islands represented only 1.9% of the study area and were mapped into seven forest classes: open (<31% green vegetation cover, 3.8%), semi-closed (31-69% green vegetation cover, 10.2%), closed hardwood (7.8%), closed mixed (36.2%), closed conifer 0-80 years (22.4%), closed conifer 81-200 years (16.7%), and closed conifer >200 years (2.9%). The rest of the study area was mapped in three successive stages as urban areas (13.0 %), valley forest (26.3%), and non-forest (58.8%).

Urban areas

The 1802 km^2 urban area, defined by the State's urban growth boundaries, was predominantly mapped into three built classes using a subjective standard for the level of development: built high-density (10.3%), built medium-density (35.6%), and built low-density (4.5%). The remainder of the urban areas was mapped as pasture/natural (14.1%), field crop (9.6%), orchard (7.3%), forest closed hardwood (7.1%), forest closed mixed (4.6%), and water (2.1%). Nine other classes combined to account for less than 5% of the area.

Table 3.6. Photointerpretation error matrix (see Table 3.4 for code definitions).

Photo Interpretation	FSA Crop Report Reference														
	BER	**CO**	**ERC**	**F**	**FC**	**G**	**IFC**	**LFC**	**M**	**O**	**P**	**R**	**RC**	**X**	**Total**
BER	**1**														1
CO		**1**													1
ERC			**1**									1			2
F				**3**		1		1					1		6
FC					**40**	4		2			1				47
G						**26**									26
IFC				1			**4**								5
LFC								**2**			1				3
M									**3**						3
O										**8**					8
P				1	1	1					**16**				19
R												**3**			3
RC					1		1						**25**		27
X														**2**	2
Total	1	1	1	5	42	32	5	5	3	8	18	4	26	2	153
Accuracy (%)	100	100	100	60	95	81	80	40	100	100	89	75	96	100	**88.2**

Valley forest

We labeled 3642 km^2 of the study area as valley forest, defined as forest with at least 70% canopy closure, and further distinguished this cover type into five classes based on the estimated percentages of hardwood and conifer (Cohen et al. 2001): closed hardwood (22.1%), closed mixed (37.6%), closed conifer 0-80 years (20.0%), closed conifer 81-200 years (16.8%), and closed conifer >200 years (3.4%).

Valley non-forest

In the remaining 8127 km^2 of non-forested area, we mapped the landscape into 17 land cover classes, including a small percentage of forest classes (5.7%) which were obtained by re-examining the pixels rejected as forest in the second classification step. The majority of this area was mapped as field crop (37.7%) or pasture/natural (34.2%), two land cover types which are prevalent in the valley. Other important land cover classes included row crop (6.7%), orchard (4.1%), bare/fallow (3.3%), built low density (2.9%), and water (2.3%). The 28 km^2 of pixels covered with cloud and cloud shadow were then classified into the same land cover types using a cloud-free training set.

Willamette Valley land cover map

The final map was created by combining the three stages of this study with the existing upland forest map (Figure 3.5) to generate a 20-class map of the study area (Figure 3.7). These classes are presented in Table 3.7, which reveals that the most dominant land cover types in the valley are field crop (23.4%), pasture/natural (23.4%), and forest closed mixed (12.5%). The error matrix for the map (Table 3.8), excluding the closed conifer age classes, indicates an overall map accuracy of 73.8%. The accuracy assessment for the closed conifer forest age classes was performed independently, using ground reference sample points from the upland forest region (Cohen et al. 2001). Table 3.9 shows a closed conifer forest age accuracy of 77.5%.

The final 20-class Willamette Valley land cover map portrays a landscape in which land use is determined by topography, access to irrigation, and urbanization.

Table 3.7. Final land cover classes for Willamette Valley study area.

Class	Area (km²)	%
Bare/fallow	276.9	2.0
Built high density	228.4	1.7
Built low density	315.3	2.3
Built medium density	642.0	4.6
Field crop	3233.8	23.4
Flooded/marsh	88.6	0.6
Forest closed conifer 0-80 yrs.	872.2	6.3
Forest closed conifer 81-200 yrs.	743.9	5.4
Forest closed conifer >200 yrs.	170.9	1.2
Forest closed hardwood	1046.8	7.6
Forest closed mixed	1727.9	12.5
Forest open	9.7	0.1
Forest semi-closed	26.2	0.2
Hops	33.0	0.2
Mint	28.7	0.2
Orchard	460.6	3.3
Park	92.2	0.7
Pasture/natural	3032.7	21.9
Row crop	570.5	4.1
Water	226.0	1.6
Total	**13826.3**	**100.0**

Most of the built pixels are found within the major urban centers of Portland, Salem, and Eugene (Figures 3.1 and 3.7). In the flat southern portion of the valley, characterized by deep silty soils, the predominant land cover is field crop, exemplified best by rye grass grown for seed. In the vicinity of the Willamette River and its major tributaries, the availability of surface water for irrigation makes row crop farming feasible, as well as other lucrative crops such as mint, hops, and orchards. The greatest diversity of crop types is found north of Salem and outside Portland, where farm tracts are smaller and more varied than in the south. Where foothills break the valley floor, the pasture/natural class dominates. This class includes pastures, shrub lands, oak savanna, vineyards and Christmas tree plantations. Along the fringe of the valley toward the Coast Ranges and the Cascades, pasture/natural cover gives way to closed forest, including vast oak and conifer stands.

Table 3.8. Error matrix for land cover classes.

Map Prediction	Reference																	
	B/F	BHD	BLD	BMD	FC	FL	FCC	FCHW	FCM	H	M	O	PK	P/N	RC	W	Total	Accuracy (%)
Bare/fallow (B/F)	**21**	1			1							2		1	3		29	72.4
Built high density (BHD)		**9**	1												1		11	81.8
Built low density (BLD)		3	**6**											2			11	54.5
Built medium density (BMD)			3	**10**										2			15	66.7
Field crop (FC)					**175**	3					3	4	1	17	17		220	79.5
Flooded/marsh (FL)						**4**											4	100.0
Forest closed conifer (FCC)							**44**		11					4			59	74.6
Forest closed hardwood (FCHW)								**31**	1			4		1			37	83.8
Forest closed mixed (FCM)							3	12	**16**					2			33	48.5
Forest semi-closed					1									2			3	0.0
Hops (H)										**17**				1	2		20	85.0
Mint (M)					3						**10**				2		15	66.7
Orchard (O)	2				1							**32**		6		1	42	76.2
Park (PK)					1							1	**2**	1			5	40.0
Pasture/natural (P/N)	1		8		17		1	1		3		11		**73**	3		118	61.9
Row crop (RC)	1				13					1					**77**		92	83.7
Water (W)																**1**	1	100.0
Total	25	13	18	10	212	7	48	44	28	21	13	54	3	112	105	2	715	
Accuracy (%)	84.0	69.2	33.3	100.0	82.5	57.1	91.7	70.5	57.1	81.0	76.9	59.3	66.7	65.2	73.3	50.0		**73.8**

Table 3.9. Closed conifer forest age error matrix.

	Reference				
Map Prediction	**1-80yrs**	**81-200yrs**	**>200yrs**	**Total**	**Accuracy (%)**
1-80 yrs.	**15**	4		19	78.9
81-200 yrs.	5	**20**	2	27	74.1
>200 yrs.		5	**20**	25	80.0
Total	20	29	22	71	
Accuracy (%)	75.0	69.0	90.9		**77.5**

DISCUSSION

Desired versus mapped classes

The main objective of this project was to deliver a map of the Willamette Valley which matched a list of desired land use and land cover classes (Table 3.2). Many of those classes, especially in the urban, built, and hydro groups, were essentially land use designations, which "convey the human employment of the land," as opposed to land cover classifications, which "denote the physical state of the land" (Turner and Meyer 1994). We knew at the onset that we would be unable to map certain land use classes with TM imagery, but that many of those classes could be mapped with ancillary GIS data, such as census data, zoning information, and transportation coverages. Therefore, we were more concerned with detecting spatial variation within the forested, agriculture, and open/woody classes.

For both the forested and the non-forested portions of the valley, we collected ground reference data which reflected both the desired class list as well as the full landscape diversity of the valley. The combination of a rich ground reference data set (Table 3.3) with a nearly exhaustive non-forest cover scheme (Table 3.4) allowed us to finely separate the TM imagery into unique land cover classes. To isolate the forested portion of the valley, we generated percent forest cover data for over 200 photointerpreted plots, similar to the methods of Cohen et al. (2001). In the non-forest, we used a combination of the FSA slides and the multi-date Tasseled Cap images to

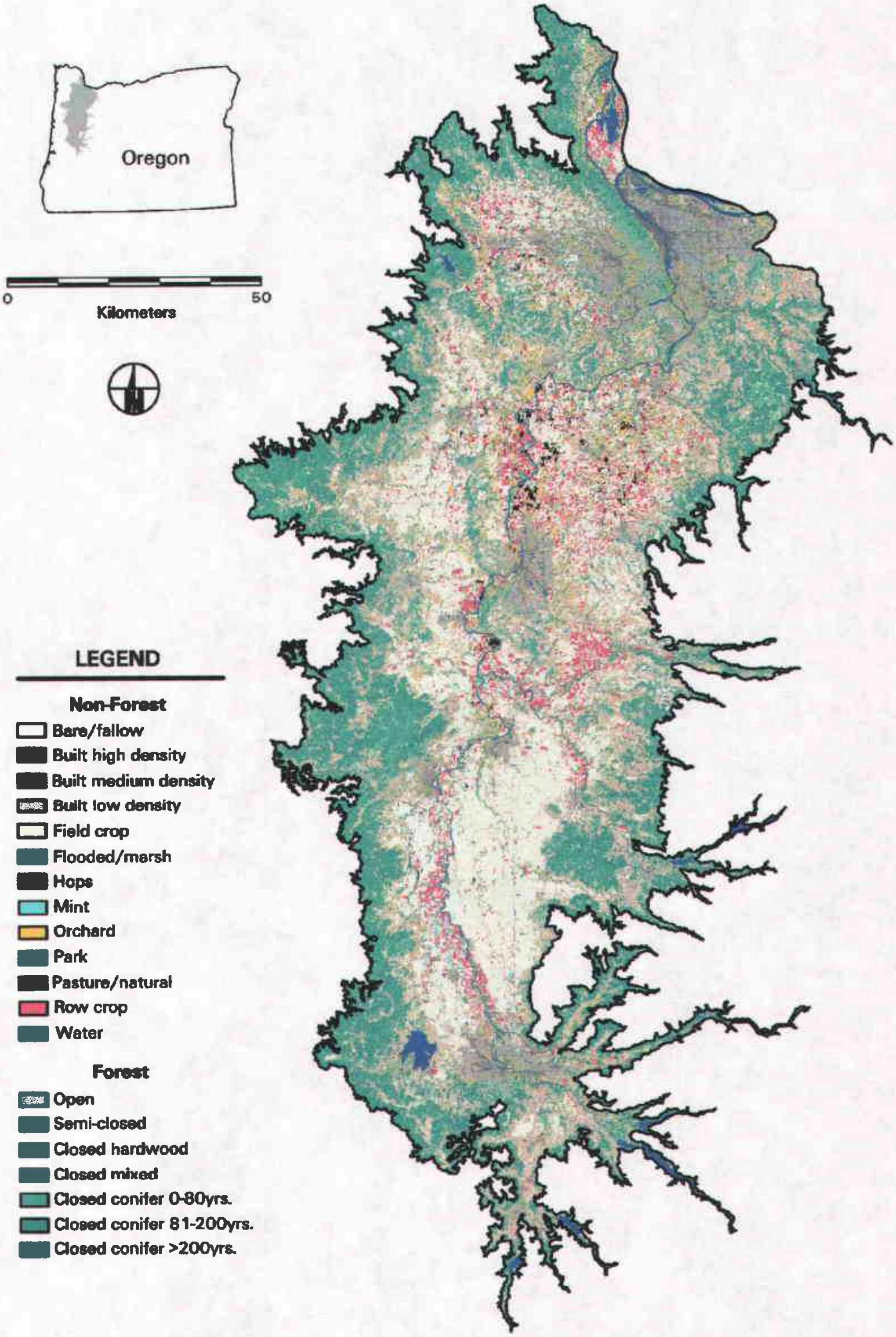

Figure 3.7. 1992 20-class land cover map of the Willamette Valley.

identify over 50 unique types of agricultural and natural land cover, distributed over a wide geographic range (Figure 3.4). Our photo interpretation of the more common land cover classes was independently verified by FSA crop reports (Table 3.6). Having confidence in our photointerpretation, combined with the broad diversity and areal representation of the ground reference data set, gave us a considerable advantage in using a supervised classification to separate the non-forest pixels into 20 final classes (Table 3.7).

The rich five-date TM data set allowed us to map many classes which could not have been captured without multi-seasonal imagery (Lo et al. 1986, Williams et al. 1987). A different map of the basin (Uhrich and Wentz 1999), which used June and August, 1992 images for the WRB, mapped nine land cover classes (urban, water, mature forest, regrowth forest, non-forest upland, native vegetation-valley floor, irrigated crops, grass fields/small grains, and perennial snow). The addition of three additional dates allowed us to separate the non-forested portion of the valley into nine classes other than water and built. For example, the bare/fallow class was discernable because we knew that throughout that growing season, there was no green vegetation cover on those fields. Likewise, the flooded/marsh class required having imagery from the wet season (March), as well as throughout the rest of the growing season in order to differentiate seasonal wetlands from permanent water bodies.

Not surprisingly, the spectral separability of the TM imagery did not match the highly refined ground reference data set, and we were unable to capture the full complement of known land cover types in the valley. Many of our initial classification results were later aggregated into broader classes (e.g., pasture, natural grasslands, natural shrub, and Christmas trees were combined to form one pasture/natural class). Other spectrally distinct classes were collapsed into final classes either because they represented very small percentages of the valley (e.g., sugar beet seed), or because we lacked sufficient ground reference plots to statistically justify separate classes (e.g., closed oak forest). In addition, we were not able to map new crops such as hybrid poplar and meadowfoam which have just recently appeared on the landscape in sufficient area to warrant mapping (Table 3.10).

Table 3.10. Final map status of the classes desired by the PNW-ERC ('n/m' = not mapped).

Desired Class	Final Map Class	Comments
1. Urban		
a) Residential	n/m	Land use classification
b) Commercial	n/m	Land use classification
c) Industrial	n/m	Land use classification
d) Open Space	Park, Pasture/natural	
e) Herbaceous-roads	n/m	Spatial resolution
2. Built (Non-Urban)		
a) Commercial	n/m	Land use classification
b) RR2-5 Zoning	n/m	Land use classification
c) Within 2 acres of structures	n/m	Land use classification
d) Railroad	n/m	Spatial resolution
e) Roads	n/m	Spatial resolution
f) Revetments	n/m	Spatial resolution
3. Hydro		
a) Headwater streams	n/m	Spatial resolution
b) Open standing water	Water	
c) Streams > 1st order	Water, n/m	Spatial resolution
4. Forested		
a) 0-40 year old Douglas-fir	Forest closed conifer	Derived from continuous
b) 41-120 year old Douglas-fir	Forest closed conifer 0-80yrs.	Derived from continuous
c) > 120 year old Douglas-fir	Forest closed conifer 0-200yrs.	Derived from continuous
d) Mixed conifer / deciduous	Forest closed mixed	
e) Deciduous	Forest closed hardwood	
f) Lower riparian forest	Forest closed mixed, Forest closed hardwood	Proximity to water was not mapped
5. Agriculture		
a) Grass seed / grain	Field crop	
b) Hybrid poplar	n/m	Inadequate ground
c) Nursery operations	n/m	Spectral resolution
d) Orchards	Orchard	
e) Pasture and haylands	Pasture/natural	
f) Row crops	Row crop	
g) Vineyards, berries, and hops	Row crop, Pasture/natural, Hops	
h) Christmas trees	Pasture/natural	
i) Mint	Mint	
j) Meadowfoam	n/m	Inadequate ground
k) Confined animal operations	n/m	Inadequate ground
l) Farmsteads	Built low density	
6. Open / Woody		
a) Shrub / brush	Pasture/natural	
b) Fence rows	n/m	Spatial resolution
c) Oak savanna	n/m	Spectral resolution
d) Prairie (grass / forb)	Pasture/natural	
e) Marsh (non-treed wetlands)	Flooded/marsh	
7. Percent Impervious surface		
a) < 10%	n/m	Reflected by Built low
b) 10-20%	n/m	Reflected by Built medium
c) > 20	n/m	Reflected by Built high

Our attempt to estimate percent impervious cover within urban areas was confounded by a lack of usable ground reference data (Plunk et al. 1990). However for our final classes, we decided to create three relative levels of built land cover types (built high density, built medium density, and built low density) which would reflect the relationship between vegetation and impervious cover. The high density class mapped large buildings, parking lots, and other artificial features with minimal vegetative cover, the medium density class reflected apartment buildings and residential settings where vegetation was present but not prevalent, and the low density class represented the well vegetated suburbs where trees, shrubs, and lawns share the spectral signal more equally with roads and rooftops. As there was no available ground reference data, we could not ascertain how well these class distinctions modeled percent impervious cover. Furthermore, our mapping of the urban areas may have been limited due to our exclusion of the fourth (haze) Tasseled Cap band (Goward and Wharton, 1984).

Multi-seasonal Tasseled Cap trajectories

A second objective of our research was to extend our working knowledge of the Tasseled Cap transformation into the agricultural lowlands of the WRB. We had previously relied on ancillary GIS data to separate forest (especially hardwood) and agricultural cover in the valley (Cohen et al. 2001), but for this project we attempted to use the spectral data alone to guide the separation of forest, agricultural, and natural land cover types. In addition to conserving storage space by collapsing the data (we only employed the first three Tasseled Cap bands), the TM Tasseled Cap transformation produces bands which have physically interpretable characteristics, both in geographic space and in feature space (Kauth and Thomas 1976, Crist and Cicone 1984, Crist et al. 1986). For our trained analyst, the more familiar spectral responses of forest and shrub cover were easily distinguishable against a backdrop of spectrally unique agricultural crops. In feature space, the multi-seasonal trajectories of our training plot means were well separated in brightness-greenness (B-G) and brightness-wetness (B-W) space (Figures 6c and 6d).

A major advantage of using multi-seasonal Tasseled Cap imagery is the ability to separate land cover classes with attention to the seasonal greenness curves (Crist and Malila 1980, Lo et al. 1986). Figure 3.6a shows the confusion in B-G space that would occur by using only one date of imagery (in this case 7 June) for a supervised classification. While the forest and flooded/marsh classes may have been separable in this instance, the remaining classes appear confused in two major clusters depending on the presence or absence of vegetative cover in June. For that one date, the row crop, hops, and bare/fallow classes are indistinguishable, since all those plots reflected bare soils at that time. Similarly, the agricultural cover types that were vegetated in June (field crop, mint, and orchard) are confused with each other, and at the same time they are closely associated with pasture/natural and park cover responses.

The five-date multi-seasonal TM data set facilitated better separation of land cover classes by allowing classification of the pixels based on their temporal trajectories through the growing season. In B-G space, these trajectories can be plotted as vectors moving through time (Figures 6c and 6d). Each training reference mean is more significantly separable because it defines that cover type in 15 dimensions through time, rather than just in the three dimensions of a one-date Tasseled Cap image. The flooded/marsh class, for example, begins its path through B-G space near the water bulb (low brightness, low greenness) in March, and then increases dramatically in brightness through the growing season as the surface water and soil moisture diminish. Row crop and field crop classes are readily separable, as field crops begin the growing season with high greenness, peak in May, and drop rapidly as natural precipitation diminishes during the dry months of July and August, whereas row crops are planted later and do not green up until July. Parklands remain high in greenness throughout the growing season with the aid of irrigation and maintenance. At the other end of the spectrum, the bare/fallow class has low greenness throughout the season, and increases in brightness as the bare soil loses moisture, which is evidenced by a steep decline in wetness (Crist et al. 1984). While the mint and hops signals are separable based on the timing and direction of their feature space trajectories, the orchard and pasture/natural classes show a considerable amount of overlap in both B-G and B-W space. It is interesting to note the behavior of the orchard signal, which resembles that of the forest closed hardwood class, but with higher brightness and lower wetness. We speculate that these differences are caused by the ground cover between orchard trees. Many of the orchards we sampled were young filbert orchards with considerable gaps between trees. These gaps typically reveal grass or bare soil, which directs the orchard response away from that of forest closed hardwood. The three broad forest classes are well separated, both in the leaf-off condition in March and by the movement of the hardwood and mixed classes from more open to their closed canopy positions in both feature spaces.

The position and direction of the training class mean trajectories correlate well with the discoveries of Crist et al. 1986, who analyzed the first four bands of the Tasseled Cap transformation using both laboratory and field information. With the exceptions noted above, we observed similar feature space trajectories through the growing season. For the late-season cover types (row crop, hops, and mint), the movement from March to May was marked by sharp decrease in wetness and an increase in brightness as the bare soil dried before the growing season began. The physical interpretations of brightness, greenness, and wetness allowed us to infer a great deal of information about the vegetative cover of our study area at each of our acquisition dates. While several TM-based vegetative indices and band ratios have been applied to land cover mapping (Lo et al. 1986, Williams et al. 1987, Lauver and Whistler 1993, Pax-Lenney et al. 1996), we must conclude from our experience that a land cover mapping project such as this, across a large region with many diverse land cover types, could be accomplished with the analysis of multi-seasonal Tasseled Cap imagery (Crist 1984).

Using the map

Our purpose in this project was to produce a land cover map which would serve the needs of the PNW-ERC in their goal of characterizing the existing conditions of the WRB, both as a baseline for later research and as the starting point for the development of futures scenarios (PNW-ERC 2000). We produced a map with 20 urban, agricultural, and natural land cover classes. The PNW-ERC had a need for a great amount of detail at the expense of map accuracy, however, and elected to use an unaggregated version of our map with 40 land cover classes. That version left intact most of the finer agricultural class distinctions (which we had collapsed due to spectral resolution problems or because of their limited spatial significance) and had six age classes for closed conifer forest. The 40-class version had an overall class accuracy of 58%.

Since our work was based solely on predicting land cover from TM imagery, the first task of the consortium was to augment our map with available ancillary data, especially U. S. Census data, transportation information, and hydrology coverages. In addition, the map was amended using an agricultural projection model which employed current knowledge of irrigation withdrawal permits and county cropping statistics to predict spatial agricultural patterns for a given year. The resultant map (Existing Conditions 1990) features 60 classes, representing a wide variety of urban, forest, and non-forest land use and land cover types (PNW-ERC 2000).

The map is now being used to drive numerous ecological analyses (Table 3.1), from aquatic chemistry to the distribution of terrestrial vertebrates. For these projects, field data characterizing the present-day condition is linked to the Existing Conditions 1990 digital map to formulate relational models. Following the generation of three future scenario images (high conservation, planned trend, and high development) and one historical scenario image (for pre-European settlement conditions c. 1850), those same relational models will be used to predict past and future ecological conditions. Those predictions will then be used to inform a collective group of local stakeholders who will help guide the present-day planning process.

The major strengths of our mapping approach came from the wealth of interpretable spectral information available in our multi-seasonal Tasseled Cap imagery, especially when trained using the Farm Service Agency crop compliance photography. While we feel confident that our map product serves the needs of the consortium and other regional users, we hope to improve upon this effort in the future, perhaps by incorporating real-time ground reference data collection with the increased data availability provided by Landsat 7 and other sensors.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Environmental Protection Agency and Oregon State University for funding this research (cooperative agreement #CR824682), especially the dedicated direction of project leader Joan Baker and principal investigators Rick Edwards, Stan Gregory, and David Hulse. Although the research described in this article has been funded (wholly or in part) by the U.S. Environmental Protection Agency, it has not been subjected to the Agency's review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred. Mike Shuft, Tom Moser, Daryl Ehrensing, Michelle Ham and Patti Anderson contributed greatly to our construction of an accurate and comprehensive ground reference database, either through their suggestions for photointerpretation technique or by sharing their vast knowledge of Willamette Valley agricultural landscapes.

REFERENCES

Adinarayana, J., Flach, J. D., and Collins, W. G. (1994), Mapping land use patterns in a river catchment using geographical information systems. *Journal of Environmental Management* 42:55-61.

Bauer, M. E., Hixson, M. M., Davis, B. J., and Etheridge, J. B. (1978), Area estimation of crops by digital analysis of Landsat data. *Photogrammetric Engineering and Remote Sensing* 44:1033-1043.

Brewster, C. C., Allen, J. C., and Kopp, D. D. (1999), IPM from space: Using satellite imagery to construct regional crop maps for studying crop-insect interaction. *American Entomologist* 45:105-117.

Brisco, B., and Brown, R. J. (1995), Multidate SAR/TM synergism for crop classification in western Canada. *Photogrammetric Engineering and Remote Sensing* 61:1009-1014.

Buechel, S. W., Philipson, W. R., and Philpot, W. D. (1989), The effects of a complex environment on crop separability with Landsat TM. *Remote Sensing of Environment* 27:261-272.

Carbone, G. J., Narumalani, S., and King, M.. (1996), Application of remote sensing and GIS technologies with physiological crop models. *Photogrammetric Engineering and Remote Sensing* 62:171-179.

Christy, J. Personal communication. The Nature Conservancy, Oregon Field Office, 821 SE 14th Ave., Portland, Oregon 97214.

Cohen, W. B., and Spies, T. A. (1992), Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery. *Remote Sensing of Environment* 41:1-17.

Cohen, W. B., Spies, T. A., and Fiorella, M. (1995), Estimating the age and structure of forests in a multi-ownership landscape of western Oregon, U. S. A. *International Journal of Remote Sensing* 16:721-746.

Cohen, W. B., and Fiorella, M. (1998), Comparison of methods for detecting conifer forest change with Thematic Mapper imagery. In *Remote Sensing Change Detection: Environmental Monitoring Methods and Applications* (R.S.Lunetta and C.D. Elvidge, Eds.), Ann Arbor Press, Chelsea, Michigan, pp. 89-102.

Cohen, W. B., Fiorella, M., Gray J., Helmer E., and Anderson K. (1998), An efficient and accurate method for mapping forest clearcuts in the Pacific Northwest using Landsat imagery. *Photogrammetric Engineering and Remote Sensing* 64:293-300.

Cohen, W. B., Maiersperger, T. K., Spies, T. A., and Oetter, D. R. (2001), Modeling forest cover attributes as continuous variables in a regional context with Thematic Mapper data. *International Journal of Remote Sensing* 22(12):2279-2310.

Coppin, P. R., and Bauer, M. E. (1996), Digital change detection in forest ecosystems with remote sensing imagery. *Remote Sensing Reviews* 13(3-4):207-234.

Crist, E. P. 1984. Effects of cultural and environmental factors on corn and soybean spectral development patterns. *Remote Sensing of Environment* 14:3-13.

Crist, E. P., and Cicone, R. C. (1984), A physically-based transformation of Thematic Mapper data- the TM Tasseled Cap. *IEEE Transactions on Geosciences and Remote Sensing* GE-22:256-263.

Crist, E. P., Laurin, R., and Cicone, R. C. (1986), Vegetation and soils information contained in transformed Thematic Mapper data. *Proceedings of IGARSS' 86 Symposium*, Zurich, 8-11 Sept. 1986, pp. 1465-1470.

Crist, E. P., Laurin, R., Colwell, J. E., and Kauth, R. J. (1984), *Investigations of Vegetation and Soils Information Contained in Landsat Thematic Mapper and Multispectral Scanner Data (Final Report 160366-101-F),* Environmental Research Institute of Michigan, Ann Arbor.

Crist, E. P., and Malila, W. A. (1980), A temporal-spectral analysis technique for vegetation applications of Landsat. In *Proceedings of the 14th International Symposium on Remote Sensing of Environment,* San Jose, Costa Rica, pp. 1031-1040.

Eckhardt, D. W., and Verdin, J. P. (1990), Automated update of an irrigated lands GIS using SPOT HRV imagery. *Photogrammetric Engineering and Remote Sensing* 56:1515-1522.

Ehrensing, D. Personal communication. Department of Crop and Soil Science, Oregon State University, Corvallis, Oregon 97331.

Ehrlich, D., Estes, J. E., Scepan, J., and McGwire, K. C. (1994), Crop area monitoring with an advanced agricultural information system. *Geocarto International* 9:31-42.

[EPA] Environmental Protection Agency, Western Ecology Division, National Health and Environmental Effects Research Laboratory (1997), *Pacific Northwest Research Program, May 1997 Peer Review,* Corvallis, Oregon.

[FEMAT] Forest Ecosystem Management Assessment Team. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. 1993. Washington, D. C., USDA Forest Service.

Franklin, J. F., and Dyrness, C. T. (1988), *Natural Vegetation of Oregon and Washington,* Oregon State University Press, Corvallis, Oregon.

Goodman, M. S. (1964), Criteria for the identification of types of farming on aerial photographs. *Photogrammetric Engineering* 30:984-990.

Goward, S. N., and Wharton, S. W. (1984), Use of the TM Tasseled Cap transform for interpretation of spectral contrasts in an urban scene. In *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data,* Purdue University, West Lafayette, Indiana, 12-14 June 1984, pp. 84-88.

Haack, B., Bryant, N., and Adams, S. (1987), An assessment of Landsat MSS and TM data for urban and near-urban land-cover digital classification. *Remote Sensing of Environment* 21:201-213.

Hewitt, M. J., III. (1990), Synoptic inventory of riparian ecosystems. *Forest Ecology and Management* 33/34:605-620.

Henebry, G. M. (1993), Detecting change in grasslands using measures of spatial dependence with Landsat TM data. *Remote Sensing of Environment* 46:223-234.

Hulse, D., Flaxman, M., Richey, D., Goorjian, L., Diethelm, D., Freemark, K., White, D., Hummon, C., Eilers, J., Bernert, J., and Radosevich, S. (1999), *Possible Futures for the Muddy Creek Watershed, Benton County, Oregon,* http://ise.uoregon.edu/Muddy/Muddy_abstract.html.

Jackson, P. L., and Kimerling, A. J. (1993), *Atlas of the Pacific Northwest,* Oregon State University Press, Corvallis, Oregon.

Johannsen, C. L., Davenport, W. A., Millet, A., and McWilliams, S. (1970), The vegetation of the Willamette Valley. *Annals of the Association of American Geographers* 61:286-302.

Kauth, R. J., and Thomas, G. S. (1976), The Tasseled Cap- a graphic description of the spectra-temporal development of agricultural crops as seen by Landsat. In *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data,* Purdue University, West Lafayette, Indiana, 6 June-2 July, 1976, pp. 4b:41-51.

Kennedy, R. E., and Cohen, W. B. (In press), Automated designation of tie-points for multiple-image coregistration. *International Journal of Remote Sensing.*

Lauver, C. L., and Whistler, J. L. (1993), A hierarchical classification of Landsat TM imagery to identify natural grassland areas and rare species habitat. *Photogrammetric Engineering and Remote Sensing* 59:627-634.

Lo, T. H. C., Scarpace, F. L., and Lillesand, T. M. (1986), Use of multitemporal spectral profiles in agricultural land-cover classification. *Photogrammetric Engineering and Remote Sensing* 52:535-544.

Lunetta, R. S., and Balogh, M. (1999), Application of multi-temporal Landsat 5 TM imagery for wetland identification. *Photogrammetric Engineering and Remote Sensing* 65:1303-1310.

Moser, T. Personal communication. Dynamac Corp., 200 SW 35th St., Corvallis, Oregon 97333.

Munro, D. C., and Touron, H. (1997), The estimation of marshland degradation in southern Iraq using multitemporal Landsat TM images. *International Journal of Remote Sensing* 18:1597-1606.

[ODA] Oregon Department of Agriculture (1999) *1997-1998 Oregon Agriculture and Fisheries Statistics,* http://www.oda.state.or.us/oass/con98.htm.

Omernik, J. M. (1987), Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77:118-125.

Panigrahy, S., and Sharma, S. A. (1997), Mapping of crop rotation using multidate Indian Remote Sensing Satellite digital data. *ISPRS Journal of Photogrammetry and Remote Sensing* 52:85-91.

Pax-Lenney, M., Woodcock, C. E., Collins, J. B., and Hamdi, H. (1996), The status of agricultural lands in Egypt: The use of multitemporal NDVI features derived from Landsat TM. *Remote Sensing of Environment* 56:8-20.

Pax-Lenney, M., Woodcock, C. E. (1997), Monitoring agricultural lands in Egypt with multitemporal Landsat TM imagery: How many images are needed? *Remote Sensing of Environment* 59:522-529.

Plunk, D. E., Jr., Morgan, K., and Newland, L. (1990), Mapping impervious cover using Landsat TM data. *Journal of Soil and Water Conservation* 45:589-591.

[PNW-ERC] Pacific Northwest Ecosystem Research Consortium (2000) *The Pacific Northwest Ecosystem Research Consortium.* http://www.orst.edu/dept/pnw-erc/index.htm.

Ryerson, R. A., Dobbins, R. N., and Thibault, C. (1985), Timely crop area estimates from Landsat. *Photogrammetric Engineering and Remote Sensing* 51:1735-1743.

San Miguel-Ayanz, J., and Biging, G. S. (1997), Comparison of single-stage and multi-stage classification approaches for cover type mapping with TM and SPOT data. *Remote Sensing of Environment* 59:92-104.

Schriever, J. R., and Congalton, R. G. (1995), Evaluating seasonal variability as an aid to cover-type mapping from Landsat Thematic Mapper data in the Northeast. *Photogrammetric Engineering and Remote Sensing* 61:321-327.

Shueb, S., and Atkins, P. (1991), Crop area estimation: A comparison of remote sensing and census methods. *Geography* 76:235-239.

Towle, J. C. (1982), Changing geography of Willamette Valley woodlands. *Oregon Historical Quarterly* 83:67-86.

Tuchmann, E. T., Connaughton, K. P., Freedman, L. E., and Moriwaki, C. B. (1996), *The Northwest Forest Plan: A Report to the President and Congress,* USDA Office of Forestry and Economic Assistance, Portland, Oregon.

Turner, B. L., II, and Meyer, W. B. (1994), Global land-use and land-cover change: An overview. In *Changes in Land Use and Land Cover: A Global Perspective* (W. B. Meyer and B. L. Turner II, Eds.) Cambridge University Press, Cambridge, pp. 3-10.

Uhrich, M. A., and Wentz, D. A. (1999), *Environmental Setting of Willamette Basin (Water Resources Investigation Report 97-4082-A),* USGS National Water Quality Assessment Program, Portland, Oregon.

Vogelmann, J. E. (1988), Detection of forest change in the Green Mountains of Vermont using Multispectral Scanner data. *International Journal of Remote Sensing* 9:1187-1200.

Willamette Valley Livability Forum (1999), *About the Willamette Livability Forum,* http://www.econ.state.or.us/wvlf/.

Williams, V. L., Philipson, W. R., and Philpot, W. D. (1987), Identifying vegetable crops with Landsat Thematic Mapper data. *Photogrammetric Engineering and Remote Sensing* 53:187-191.

Wolter, P. T., Mladenoff, D. J., Host, G. E., and Crow, T. R. (1995), Improved forest classification in the Northern Lake States using multi-temporal Landsat imagery. *Photogrammetric Engineering and Remote Sensing* 61:1129-1143.

Zhuang, X., Engel, B. A., Baumgardner, M. F., and Swain, P. H. (1991), Improving classification of crop residues using digital land ownership data and Landsat TM imagery. *Photogrammetric Engineering and Remote Sensing* 57:1487-1492.

CHAPTER 4

RIPARIAN LAND COVER CHANGE DETECTION ALONG THE WILLAMETTE RIVER, OREGON

Doug R. Oetter

Manuscript to be submitted to:
Photogrammetric Engineering and Remote Sensing
American Society for Photogrammetry and Remote Sensing,
Bethesda, MD.

ABSTRACT

The Willamette River in northwest Oregon has been subjected to a wide variety of human impacts, including riparian forest removal, channelization, and severe water pollution. As resource managers examine ways to conserve existing riparian resources and restore parts of the historic floodplain, it has become crucial to characterize recent land cover change along the river. This study used Landsat imagery to detect and classify land cover change within the Willamette River floodplain for three time periods (1970's, 1980's, and 1990's), which coincide with the implementation of the Willamette River Greenway land use planning goal. The methodology employed both image differencing and image classification, joined with ancillary GIS data layers in an expert classification routine. Eight broad land cover types were used to map 27 change classes. Although 98% of the study area was classified as No change through the time periods, the methodology captured substantial change, grouped into three ecological classes: progressive change, regressive change, and land/water change. The amounts varied by proximity to the river, with the area closest to the river showing the greatest land/water change, and major tributaries contributing the most progressive and regressive change.

Keywords: Landsat, change detection, expert classification, riparian land cover, Willamette River.

INTRODUCTION

Recently there has been a dramatic increase in public regard for rivers and riparian landscapes. In the past, riparian forests were routinely cleared for agricultural expansion, river channelization, and to fuel steamboat transportation. During the twentieth century, however, as public attention to pollution issues grew and the economic advantages of river navigation diminished, scientists and the public learned to value rivers as ecologically important parts of the natural landscape (Malanson 1993). The riparian zones along river fringes receive special attention for their natural functions, which enhance water quality, wildlife habitat, flood abatement, and recreational opportunities (Naiman et al. 1988; Smith and Hellmund 1993; Gurnell 1997). There are now many substantial efforts to both conserve existing natural habitat and restore natural functions by removing levees and replanting forests along mainstem rivers (Boon 1992; Allan and Flecker 1993; Bayley 1995; Llewellyn et al. 1996).

Perhaps regrettably, this newfound attention follows a long legacy of human alteration of the nation's rivers (Graf 2001). Remnant forests exist as fragmented pieces separated by vast extents of agricultural, suburban, and built environments (Kleiman and Erickson 1996). To protect and restore natural floodplain forests, suitable sites must be located in areas that are already fully allocated for human uses (NRC-CRAE 1992). One challenge for these efforts is to map the past floodplain characteristics and the present land cover, and to incorporate this information into a present-day selection model to determine the best place to focus conservation and restoration efforts (Russell et al. 1997).

Mapping existing riparian vegetation can be especially difficult because much of the riparian habitat exists as an ecotone, or boundary between aquatic and terrestrial landscapes (Smith and Hellmund 1993). In addition, rivers are highly dynamic, with seasonal and annual floods changing both the channel and the surrounding landscape. Methods of mapping riparian vegetation range from ground-level field surveys and cable-guided balloons to airborne sensors and space satellites (Milton et al. 1995). The spatial resolution attainable is a function of which methods are used. Typically, this decision depends on the level of information needed and the funding available, as well as the type of environment being mapped (Lee and Lunetta 1995; Muller 1997). Certainly, satellite remote sensing is more effective for detecting the presence or absence of riparian vegetation in a desert (Lee and Marsh 1995) than for determining the species composition of a closed canopy forest (Congalton et al. 2000).

The use of low altitude aerial platforms is most useful in studies where either the spatial extent is relatively small or the required level of detail is relatively high (Hoar and Erwin 1985; Christensen et al. 1988; Johnson 1994; Neale 1997; Williams and Lyon 1997; Dixon and Johnson 1999; Weber and Dunno 2001; Moser et al. 2002). Because air photo interpretation over a large spatial extent can be cost-prohibitive, however, satellite-based sensors are common for regional-scale studies where the accurate resolution of species- and community-level vegetation patterns is not required (Wickware and Howarth 1981; Hewitt 1990; Michener and Houhoulis 1997; Narumalani et al. 1997; Kovacs et al. 2001). Satellite sensors allow for relatively inexpensive mapping of large spatial extents, and their multiple spectral bands are effective for discrimination of land cover and broad vegetation patterns (Muller et al. 1993; Iverson et al. 2001).

Study area

The Willamette River in northwestern Oregon drains a 29,700-km^2 basin dominated by forestry and farming (Figure 4.1). With an annual average flow at Portland of over 900 m^3/s, the Willamette River is the thirteenth largest river in the United States, and it has the added distinction of being one of the few rivers in the lower 48 states which flows north. Over its 300 km course from south of Eugene to the Columbia river north of Portland, the river weaves through extensive agricultural regions and past five of the six largest cities in the state. Over two-thirds of Oregon's population of 3,400,000 lives in the Willamette basin, and that figure is expected to double by 2050 (Hulse et al. 2002).

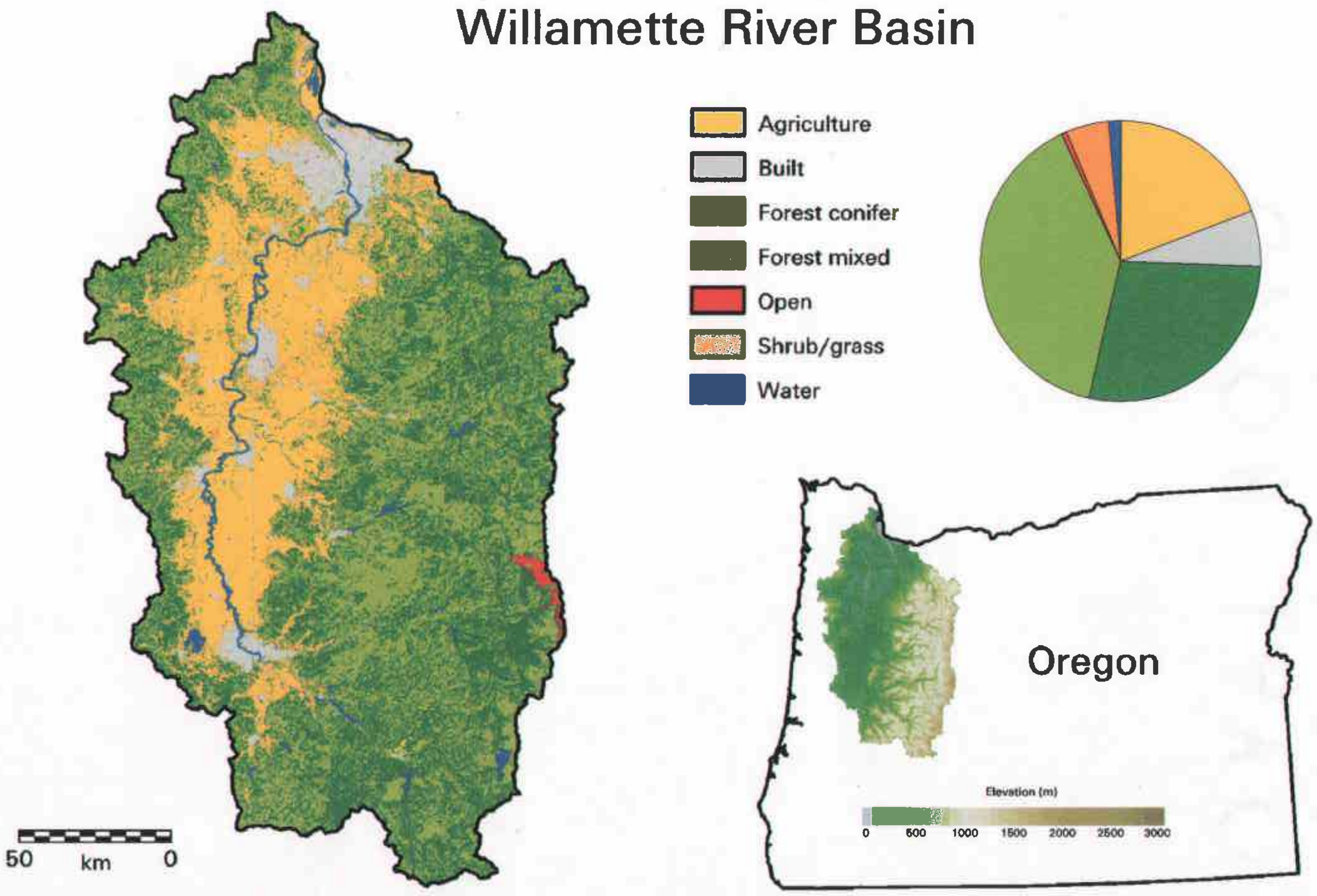

Figure 4.1. The Willamette River Basin in northwest Oregon. Land cover types from Oetter et al. (2001) are shown in the main map and pie chart; elevation is shown in the inset.

As with most human-impacted rivers, the Willamette River has been exploited for a variety of resources in the past (Gleeson 1972; Honey 1975; Muckleston 1986), and as a result the riparian landscape has changed dramatically in the 170 years since European settlement in the valley (Sedell and Froggatt 1984; Benner and Sedell 1997). In recent history, the Willamette River has been the subject of much study, partly in response to the decline of a once-thriving Pacific salmon population. Excessive waste effluents from pulp mills and municipalities inspired a major effort to improve water quality in the river from the 1930's to the 1960's. Following the construction of several wastewater treatment plants and upstream storage reservoirs, the river's water quality showed remarkable improvement by 1966 (Starbird 1972; Leland et al. 1997).

That year saw a Governor-lead conservation initiative to protect against anticipated urban growth along the river. Through a long political process, the idea eventually culminated in the creation of the Willamette River Greenway (WRG) in 1975 (Bauer 1980). The WRG is a land-use zoning restriction designed to limit the conversion of farmlands and forests along the river into more intensive uses (Little 1990). While it does not specifically prevent riparian forest removal, the greenway designation was intended "to protect, conserve, enhance and maintain the natural, scenic, historical, agricultural, economic and recreational qualities of lands along the Willamette River (OSPRB 1976)." The WRG boundary was drafted to include riparian land within 50 m (at a minimum) of the normal high-water mark of the river, as well as many important natural lands along the river.

More recently, extensive flooding in 1996 demonstrated a need to restore natural riparian floodplains as an additional flood control measure to upstream storage (Gardiner 1999). Where there were once extensive riparian forests capable of mitigating the impacts of intense floods, there are now agricultural fields and levees which speed the flow of water downstream. The proponents of riparian restoration contend that in addition to providing buffering capacity for excessive flood waters, the re-creation of bottomland hardwood forests and removal of channel structures would improve habitat conditions for endangered salmon runs (Frenkel et al. 1991; Gregory 1999; Willamette Restoration Initiative 2001; Willamette Riverkeeper 2002).

Essential tasks for both the conservation and the restoration efforts are characterizing the historical floodplain condition and detecting landscape change along the river in the recent past. Answering these two questions would allow researchers to determine what part of the floodplain is most susceptible to conversion pressure and to identify the best potential restoration sites. Two companion manuscripts report on recently completed research to characterize the historical floodplain channel condition, as well as channel and riparian vegetation change from pre-settlement conditions to present (Gregory et al. in press; Oetter et al. in review).

To examine more recent changes, studies have detailed local vegetation responses to the hydraulic modifications caused by upstream dams and channel modifications (Gutowsky 2000; Dykaar et al. 2000). As with other regulated rivers, dams above the Willamette River have reduced the intensity and frequency of major floods, so that riparian vegetation is becoming more stable as disturbances are reduced (Hupp and Osterkamp 1985; Johnson 1997). In addition, channel hardening from riprap and other structures has confined the channel and removed potential floodplain from the hydraulic system (Sedell and Froggatt 1984; Hulse et al. 2002).

At the same time, population growth and urban expansion have also exerted their influence on the Willamette River riparian landscape. A particular concern voiced by Frenkel et al. (1984) is that riparian lands are being converted to ecologically regressive uses in spite of the WRG designation. Their study demonstrated a conversion of 12.6% of the natural vegetation cover to agriculture and development in a nine-year period in Benton and Linn counties. The authors concluded that the greenway designation was ineffective as a conservation device, and that development-driven landscape conversion and surface gravel mining would likely continue to impact the riparian landscape.

Objectives

The main objective of this research is to update and expand upon the work done by Frenkel et al. (1984) by determining the direction and magnitude of riparian landscape change along the entire Willamette River from 1975-1995. To accomplish this, a secondary objective is to test the feasibility of using Landsat TM imagery to detect riparian vegetation change along a mainstem river, as opposed to the very costly and time-consuming use of aerial photographs.

Frenkel et al. (1984) employed manual interpretation of aerial photographs along a 97-km stretch of the Willamette River. To map change within the entire WRG boundary over a larger time period and spatial area, I chose to use Landsat satellite imagery instead of aerial photographs. It is important to evaluate the advantages of satellite remote sensing techniques for detecting riparian landscape change along a mainstem river.

METHODS

Reference photos and ancillary data

Essential to the interpretation of digital satellite imagery is the acquisition of a reliable ground reference data set that can be used to train and test the satellite product. For historical studies such as this, it is impossible to go back in time to conduct field studies, so the use of historical aerial photography is common. Three main sources of photographic reference were acquired for this project (Figure 4.2):

- 1973-1974 Black and white aerial photographs acquired on a flight path specifically oriented to the river to allow the delineation of the original WRG boundary (OSPRB 1976). These 107 photos were issued in large format (61 x 91 cm) at a scale of 1:1000 and then re-issued in a collection of four books in reduced format (23 x 30 cm) at a scale of roughly 1:12000. The proposed greenway boundary, as well as sites of existing gravel removal permits and boundaries of publicly-owned lands were hand drawn on the photographs before reproduction;
- 1982 and 1986 black and white aerial photographs acquired by Western Aerial Contractors (WAC, Eugene, Oregon) at a scale of 1:31680. Individual hardcopy photographs were obtained from the Map and Aerial Photography Library at the

University of Oregon, scanned into Tagged Image Format (TIF) files, and then georeferenced to an existing Landsat image using a second-order polynomial model for a pixel size of 4 m. Full coverage for the Willamette River and its tributaries was not available; 35% of the riparian study area was left uncovered;

- 1994-1995 Black and white digital orthophotographs (DOPs) flown and produced by Spencer Gross under contract to the U. S. Army Corps of Engineers and other local agencies specifically to provide a baseline for Willamette River studies. These DOPs were delivered at a spatial resolution of 2 feet, but were mosaicked into contiguous units and resampled to 1 m resolution. Their coverage includes the full extent of the Willamette River and its main tributaries.

Figure 4.2. Three dates of aerial photography ground reference used for training and testing the change detection procedure, at the confluence of the Willamette River with the Multnomah Channel north of Portland. The 1974 aerial photography book is not shown at the same scale as the two digital orthophotographs. Note the forest clearing at A and the wetland conversion at B.

In addition to the ground reference photography, other ancillary data were used to help train the classification of digital imagery in the study area. Among these were Digital Raster Graphics (DRGs), a 30 m Digital Elevation Model (DEM), a spectral texture image derived from the 1995 Landsat imagery, and three land use/land cover data sets from different sources. The DRGs were used primarily as a reference for screen digitizing. The DEM was used to develop a slope gradient image, to help differentiate flat land from hillsides. The texture image was created by calculating variance in a 3x3 window for combined brightness and greenness, and then selecting a threshold between smooth and rough spectral surfaces. Three different land use/ land cover data sets were used:

- 1978-80 Oregon Statewide Land Use Inventory maps developed for the Oregon Water Resources Department by the Environmental Remote Sensing Applications Laboratory (http://www.cof.orst.edu/cof/fr/research/ersal.php) at Oregon State University. One map was made for each of the three Willamette River Basin sub-drainages, the Upper in 1978, the Middle in 1980, and the Lower in 1979. The maps classify the basin into seven classes (Irrigated Agriculture, Non-Irrigated Agriculture, Range, Forest land, Urban, Water, and Other). The data were derived from U-2 color infrared photos (1:130,000) acquired from 1972-1980 as well as Landsat MSS data acquired in 1978-80. The paper maps were converted to digital raster images by scanning at 300 dots per inch and rectifying them to geographic coordinates to produce a 25 m image. An unsupervised classification was used to convert the background colors of the map into digital land use classes. Filtering and elimination routines were used to replace map text with the surrounding map class.
- 1983-86 Oregon Generalized Zoning Coverage produced by the Oregon Geospatial Data Clearinghouse (http://www.gis.state.or.us/data/index.html). This vector polygon coverage was digitized from county zoning maps at a scale of 1:100,000, and contained codes for 15 general land use zoning designations. It was reprojected and rasterized to 25 m pixels.
- circa 1990 Land Use/Land Cover from the Pacific Northwest Ecosystem Research Consortium (http://www.orst.edu/dept/pnw-erc/index.htm). This raster data layer divides the Willamette River Basin into 54 land use/land cover classes using a combination of a multi-seasonal Landsat TM data set from 1992 (Oetter et al. 2001) and GIS data layers for population, zoning, transportation, and agricultural information (Hulse et al. 2002).

Study area delineation

The delineation of a riparian zone of influence is the subject of much debate for ecological and legal reasons (Frissell 1986; Naiman et al. 1993; Gregory 1991;

DéCamps 1993). For this study, there are two important boundaries that were used to partition the study area. The greater of these was the Willamette River floodplain, which was delimited by mapping the full extent of several known floods from historical records (Oetter et al. in review). The 1,310-km^2 Willamette floodplain spreads across a wide plain below Eugene, is constrained occasionally by hills near Salem, and then becomes confined in a deep channel from Newberg to below Portland, where the floodplain opens to join the Columbia River (Figure 4.3).

The second boundary of interest was the WRG, which was hand-drawn on reduced format black and white photographs acquired in 1973-74 specifically for the greenway plan (OSPRB 1976). To create a digital version of the greenway boundary, the line work was screen-digitized at a scale of 1:4000 on top of the 1994-95 DOPs, as well as DRGs when the photo coverage was incomplete or difficult to interpret. On the occasion that the landscape had changed dramatically between the 1970s and 1990s photographs, such that manual placement of the WRG boundary line was impossible, that particular photo was scanned as a TIF image, georectified to the 1994-95 DOPs, and then the boundary line was hand-digitized from the rectified image. This procedure was only necessary in two instances where the river had changed its course dramatically and displaced reference landmarks.

To facilitate future comparisons, the WRG boundary was buffered outward 340 m to create a buffer area equal to the area within the greenway. In addition, the six largest tributaries of the Willamette River were included. To do this, a thalweg line was hand-digitized along the main channel of the tributary for the extent of the 1994-95 DOPs, and then a 500-m buffer zone was created along this line. Both these procedures captured an area roughly equivalent to the area inside the WRG, to allow for equal-area comparisons.

The final study area was created by combining the historical floodplain coverage with the WRG area, the greenway buffer, and the tributary buffer (Figure 4.3). Land use coverage within this area in 1992 was primarily agricultural, followed by built, suburban, forest, and other cover types (Table 4.1).

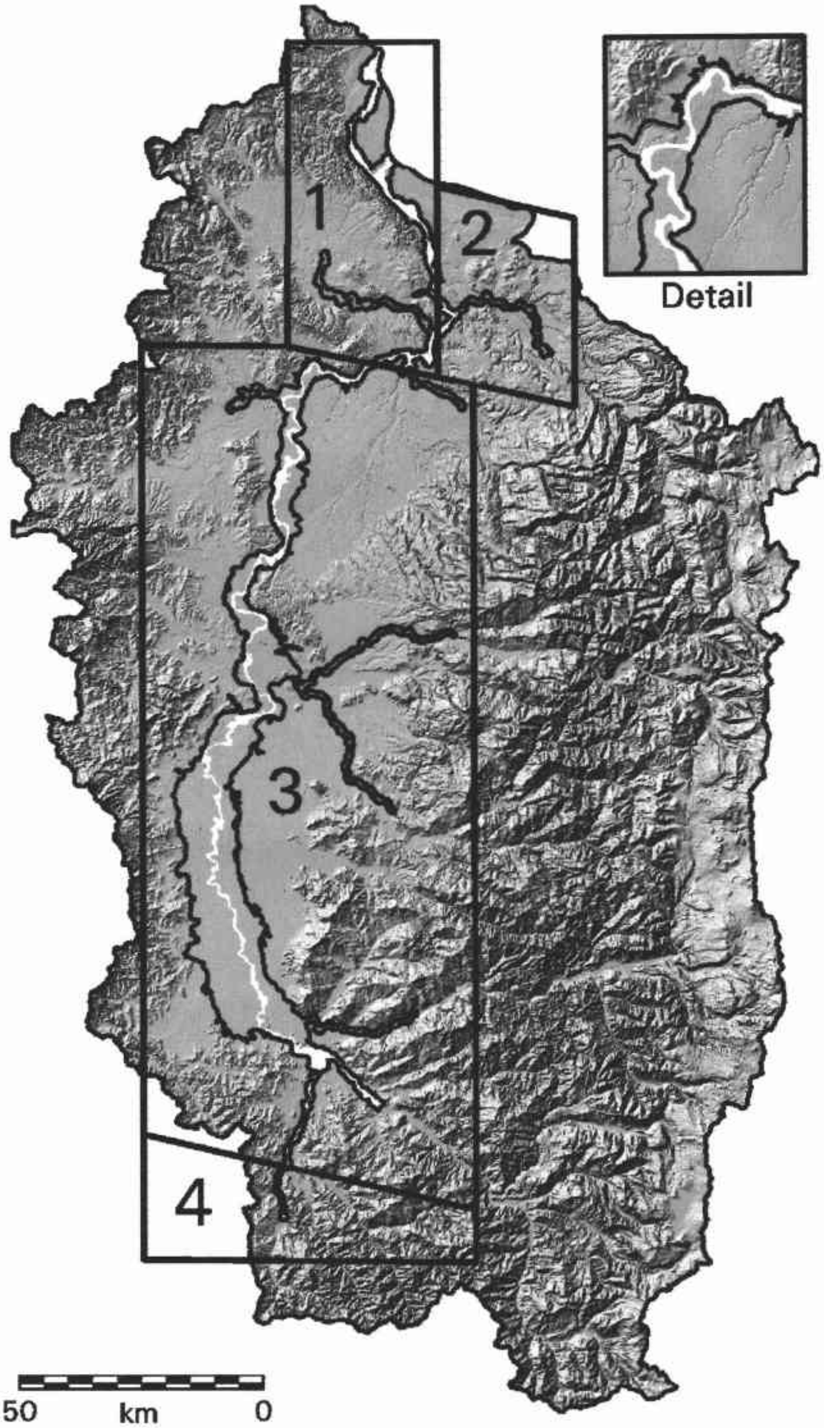

Figure 4.3. The Willamette River Greenway (solid white) and the study area boundaries (black outline) in the Willamette Valley. Extents of the four satellite image templates are shown.

Table 4.1. Pre-European settlement and c. 1990 land cover within the study area. Source for both data sets is Hulse et al. (2002).

Land cover	Pre-settlement area (ha)	%	c. 1990 area (ha)	%
Agriculture	0.0	0.0	105638.7	59.6
Built	0.0	0.0	13468.5	7.6
Forest	61893.5	34.9	23102.8	13.0
Open	225.4	0.1	3761.2	2.1
Shrub/grass	96596.7	54.5	8126.4	4.6
Suburban	0.0	0.0	10260.4	5.8
Water/wetlands	18497.8	10.4	12855.4	7.3
Total	177213.5	100.0	177213.3	100.0

Image acquisition and pre-processing

Ten separate Landsat images were used for this study (Table 4.2). These included three Multi-spectral sensor (MSS) images from the 1970's time period, four Thematic Mapper (TM) images from the 1980's, and three TM images from the 1990's. The selection of dates was designed to fit a 20-year period beginning near the initiation of the WRG program in 1975. Each image was subset to a region slightly larger than the study area. The earlier images were then georeferenced to the 1995 reference images using second order polynomial transformations based on no fewer than 25 ground control points. The root mean square error for these transformations was approximately 13 m for the TM images and 33 m for the MSS images. Rectification was not necessary for the 1988 image; it served as the original reference for 1995 images in a previous project (Cohen et al. 2001).

Following georeferencing, each image was subset to the study area. Binary mask images were created to partition the entire study area into four templates (Figure 4.3). Each template represented a unique combination of three images, one from each time period. These masks were used to confine further analyses to the maximal area shared by each image. Following this, the Tasseled Cap transformation was applied to the MSS and TM images to produce brightness and greenness indices. This transformation was used because of its proven utility for image differencing (Collins and Woodcock 1994; Cohen et. al 1998) and to enhance visual image discrimination of biophysical landscape features (Kauth and Thomas 1976; Crist and Cicone 1984). Radiometric normalization was not performed on any image pairs.

Table 4.2. Landsat images used in the study.

Satellite	Sensor	Path	Row	Acquisition Date	Ground Control Points (n)	Root Mean Square Error (m)
Unrectified Images						
Landsat 2	MSS	49	28	16-Aug-1977	25	30.7
Landsat 2	MSS	49	29	16-Jul-1976	39	37.1
Landsat 2	MSS	49	30	29-Jul-1977	25	33.5
Landsat 5	TM	46	28	4-Aug-1984	32	13.7
Landsat 5	TM	46	28	31-Aug-1988	- [a]	-
Landsat 5	TM	46	29+30[b]	17-Jun-1984	30	12.9
Reference Images						
Landsat 5	TM	46	28	19-Aug-1995	- [c]	-
Landsat 5	TM	46	29	19-Aug-1995	- [c]	-
Landsat 5	TM	46	30	3-Aug-1995	- [c]	-

a- The 1988 path 46, row 28 scene is the original reference image for the 1995 georeferencing.
b- The 1984 path 46, rows 29 and 30 images were combined to form one image.
c- The 1995 images were georeferenced in a previous study (Cohen et al. 2002).

Change detection

Change detection within the study area was accomplished using a combination of two separate digital image processing approaches and an expert classification method (Figure 4.4). Initially, brightness-greenness image differencing was applied between consecutive time periods for each study template to capture candidate pixels that might have changed. Separately, a combination of supervised and unsupervised image clustering techniques was applied to identify the initial and terminal land cover classes for each time period. The output of these two approaches was then combined with ancillary data in an expert classification routine to produce a change map for each period.

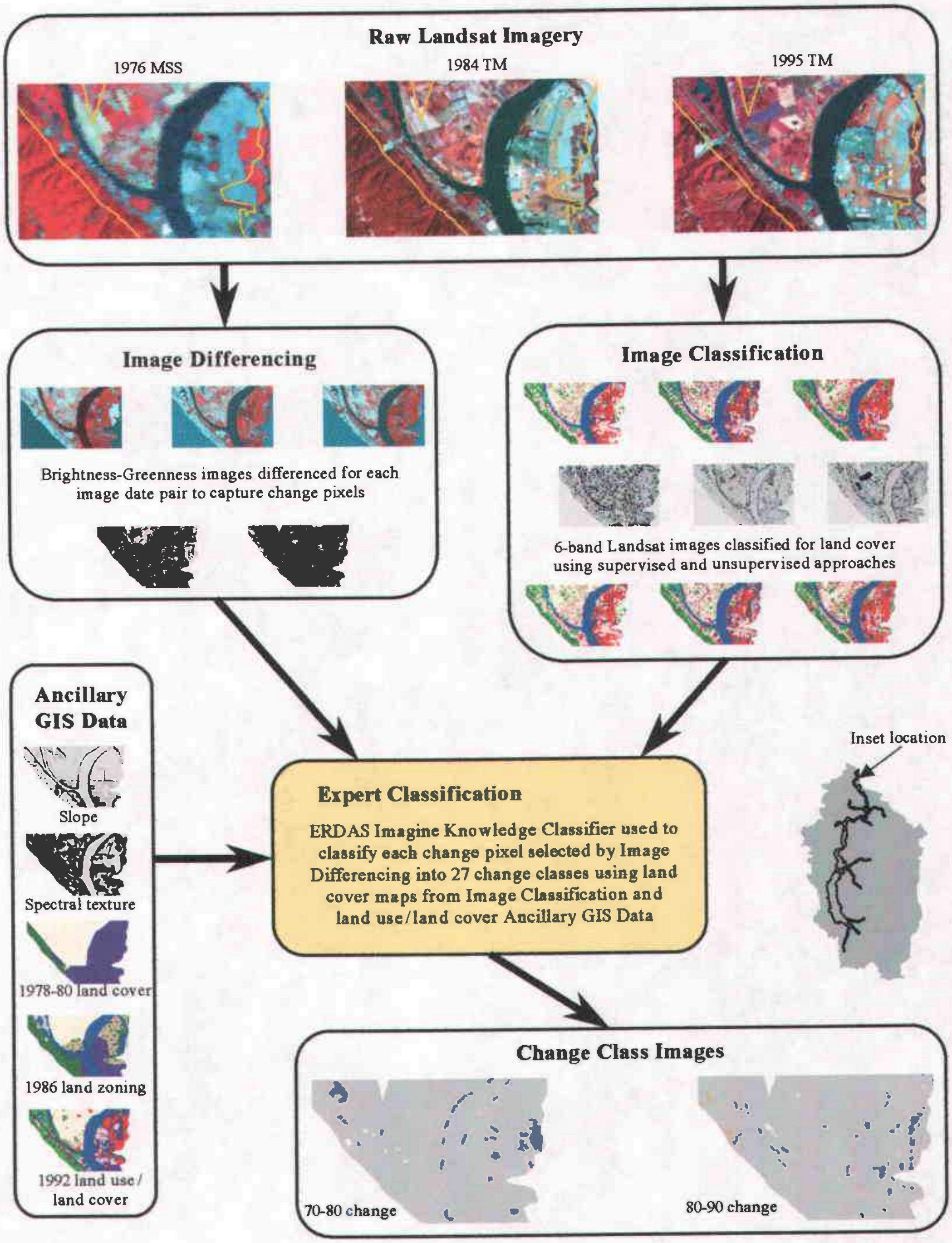

Figure 4.4. Process schematic of change detection technique. The area shown is the same as in Figure 4.2, and the study area boundary is drawn over the raw images.

Image differencing has proven effective in several recent change detection studies (Michener and Houhoulis 1997; Cohen 1998; Macleod and Congalton 1998; Kovacs et al. 2001; Hayes and Sader 2001). The Tasseled Cap transformation was used here to allow for the direct interpretation of physical landscape features in the change image (Collins and Woodcock 1994), as well as to facilitate comparisons between the MSS-TM time period (70's-80's) and the TM-TM time period (80's-90's). Within each template and time period, unscaled brightness-greenness difference images were created by subtracting each pixel's early value from its later value. To highlight potential change pixels, each difference value outside of 1.5 standard deviations from the mean was labeled as one of five classes: brighter and less green, brighter or less green, no change, darker or greener, and darker and greener. The selected threshold of 1.5 sd was based on a visual analysis of the image difference values with reference to known change locations in the raw imagery (Fung and LeDrew 1988; Muchoney and Haack 1994).

In addition to difference imaging, a combination of supervised and unsupervised classification was employed to create a land cover map for each of the 12 subset images (four templates for three dates). The combination of supervised and unsupervised approaches helps improve classification accuracy (Ehrlich et al. 1994; Miguel-Ayanz and Biging 1997; Macleod and Congalton 1998). Many hierarchical approaches begin with an unsupervised clustering to capture large, highly unique pixels, such as water, cloud, and barren ground, and then move on to use a supervised technique to cluster the remaining predominantly vegetated pixels (Lauver and Whistler 1993; Oetter et al. 2001). My approach was the opposite, however, as I began by using a supervised classification (Hewitt 1990; Neale 1997; Weber and Dunno 2001) to cluster the entire image subset into one of 22 different known land cover types (e.g. dark forest, light forest, orchards, shrub, clear water, turbid water, wetlands, built, suburban, and five different intensities of agriculture). The training signatures for this clustering came from screen-digitized polygons ranging from 0.17 to 65.5 ha, geographically spread across the full extent of each template subset. Homogeneous training polygons were digitized on top of the brightness-greenness image using photos for reference, such that the full range of brightness and greenness values was captured in the signature collection. After collecting between 56 and 157 signatures for each image (Table 4.3), the spectral location of each was examined in both brightness-greenness and band 4-band 3 feature space (Figure 4.5). Polygons that were obviously anomalous to others in the same cover type were examined and either eliminated or recoded, and feature space regions that were under-represented were filled in with additional polygons. Once the final training polygon set was established, a maximum likelihood algorithm was used to classify the full image into an equal number of classes (i.e., one output class for each training polygon). These supervised classes were then recoded into eight main land cover classes (Table 4.3).

Besides mapping traditional land cover classes such as Agriculture, Forest, Open, Shrub/grass and Water/wetlands, it was also necessary to classify Built and Suburban cover. In order to do this, certain assumptions had to be made. The Built class was reserved for land cover that was completely man-made and without vegetation, such as large buildings and parking lots. It was often spectrally confused with the Open class (Figure 4.5), which was trained with fallow fields, sandbars, and vacant lots. The Suburban class was intended to capture moderate density housing developments with a varying amount of vegetation. Because many suburbs have significant lawn, shrub, and tree cover, the Suburb class was often spectrally confused with Agriculture and Shrub/grass. While the differences in these classes were apparent in the photographic reference used to develop the training polygons, their similar spectral signatures had to be separated in a later step with an expert classifier. There was also significant confusion between Agriculture, Shrub/grass, and Water/wetlands, depending upon the amount of vegetation cover and standing water at the time of image capture. The Cloud/shadow class was applied to a minimal amount of cumulus clouds in the 1984 data.

In conjunction with the supervised classification, a distance image was calculated to provide a confidence rating for each pixel's clustering. The value of the distance image is a measure of how closely matched a pixel is to the mean spectral values of the cluster to which it was assigned. For each distance image, a confidence

Table 4.3. Training polygons used to perform supervised classification. Twenty-two interpretive codes have been collapsed into eight main land cover classes.

	Supervised Classes								
Image	**Agriculture/ orchard**	**Built**	**Cloud/ shadow**	**Forest**	**Open**	**Shrub/ grass**	**Suburban**	**Water/ wetlands**	**Total**
Template 1									
1977 MSS	27	8		20	10	3	10	17	95
1984 TM	32	12		21	10	2	11	11	99
1995 TM	35	7		27	8	6	15	16	114
Template 2									
1977 MSS	17	4		12	9		10	5	57
1988 TM	22	3		12	11		10	4	62
1995 TM	22	3		11	10	2	10	6	64
Template 3									
1976 MSS	73		6	27	11	5	12	9	143
1984 TM	76	4	12	19	9	9	11	17	157
1995 TM	69	5		21	9	5	8	16	133
Template 4									
1977 MSS	25	2		17	3	3	3	3	56
1984 TM	30	2	7	18	6	2	4	4	73
1995 TM	21	2		14	11	4	4	4	60

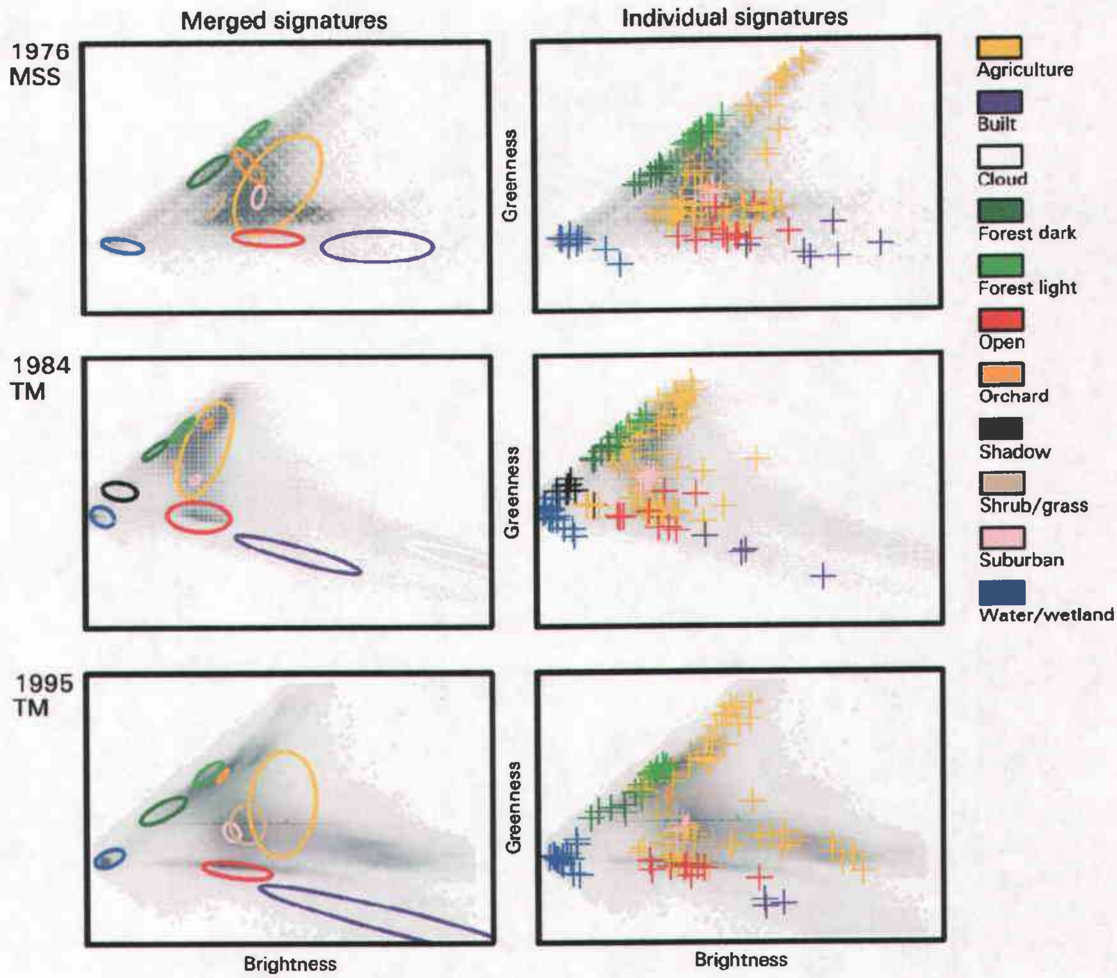

Figure 4.5. Feature space images of Template 3 for three dates with ellipses showing merged signatures (at 1 sd) and the means of individual training polygons. There was a great deal of spectral confusion among the Agriculture, Shrub/grass, and Suburb classes. Rather than train a supervised land cover classification from the merged signature set, each individual polygon was used to train an equal number of output classes, which were then collapsed into the eight broad classes used for change type analysis.

threshold was determined and uncertain pixels were subjected to a subsequent unsupervised classification. These pixels were located along land cover edges and in spectral regions that were poorly represented in the landscape, and therefore not captured in the training polygons. However, in the unsupervised classification, they were labeled as one of the main 12 land cover classes using visual reference in the raw and feature space images. Once classified, the results of the supervised classification and distance image unsupervised classification were combined to produce summary land cover images.

An expert classification routine, ERDAS Imagine's Knowledge Engineer (ERDAS 2002), was used to label the pixels detected in the image differencing procedure as either No change or one of 27 change classes. The routine classifies pixels using a sequence of rules for evaluating input data. Once the conditions have been met for a certain output class, that pixel is labeled and the routine moves to the next. The routine developed for this study took each pixel identified as change in the image differencing step and then queried the land cover classification and ancillary GIS information to label the change type (Janssen and Middelkoop 1992; Narumalani 1997). The expert classifier was especially useful in reducing the confusion between pixels that shared similar spectral characteristics, yet were entirely separate land cover classes (e.g., Agriculture, Open, Shrub/grass, and Suburban classes). The three existing land use/land cover layers were essential in providing spatial constraints to improve classification. Slope and spectral texture images were also used to help separate confused classes. The rules involved in achieving the optimal classification ranged from simple to numerous and complex, and were constructed to optimize the 'post-classification' approach of comparing the multi-date land cover classifications with the expectations of land use derived from the ancillary GIS data layers. Not all potential land cover change types were represented in the classification scheme due to lack of occurrence, for example, built to forest.

Following classification of the study area for the two time periods, a minimal amount of hand-editing was performed to recode change pixels that were misclassified due to known inconsistencies in the 1986 land use zoning coverage or the presence of thin clouds in the 1984 Path 46, Row 29 TM image. Hand-editing was rapid since only false positive pixels (i.e., No change pixels that had been misclassified as change) were corrected. Following this, the change images were filtered using a 3x3 majority window and a 0.25 ha (4 pixel) minimum mapping unit was applied to remove fine-scale noise. Finally, the four template images were mosaicked into one complete image of the full study area, and the two separate change images were combined to produce a single 1970's-90's change image.

Accuracy assessment

To test the accuracy of the change detection, over 500 test points were generated from four different sources:

- A minimum of 125 points from change pixels in the 1970's-80's image, randomly selected from change polygon centerpoints and stratified by change class frequency and geographic location;
- A minimum of 125 points from change pixels in the 1980's-90's image, randomly selected from change polygon centerpoints and stratified by change class frequency and geographic location;
- 150 points from pixels that were labeled No change in both change images, and were also detected as No change in the image differencing step, randomly selected;
- 50 points from pixels that were labeled No change in both change images, but were detected as being brighter or less green in the image differencing steps, randomly selected;
- 50 points from pixels that were labeled No change in both change images, but were detected as being less bright or greener in the image differencing steps, randomly selected.

Each testing pixel was assessed independently using the photo reference where possible. Because the 1973-74 photos only covered land along the WRG, tributaries and the floodplain area outside of the WRG buffer were not used for accuracy assessment. In addition, there were gaps in the 1982/86 and 1994-5 photo coverage. Where this occurred, in 10.0% of the test points, raw imagery was used to make a reference determination. It was not assumed that a pixel selected for assessment (because it was predicted as change in one time period) would automatically be labeled No change in the other time period. Therefore the full set of 500 points was only available to assess the combined 1970's-90's change image.

RESULTS

The delineation of the study area produced a 177,213 ha region divided into four subregions: WRG (16.3%), buffer of the WRG (16.3%), tributaries (15.7%), and floodplain area outside of those subregions (51.7%). The area of the WRG calculated here is close to the 20,886 ha reported in OSPRB (1976).

Four Landsat scene templates (Figure 4.2) were created to partition the satellite imagery into unique temporal combinations. By far, the largest of these was template 3, which contained 84.1% of the study area, followed by template 1 (12.2%), template 2 (3.1%), and template 4 (0.6%). Consequently, Template 3 had the most training polygons for the supervised classification (Table 4.3).

The change detection routine produced 28 output classes, including No change and Cloud/shadow for three separate temporal combinations (Table 4.4). By far, the most represented class was No change, with 98% of the pixels in each change image. The other 27 classes were distributed among the remaining 2% of pixels. Both the 1970's-80's and 1980's-90's change images showed the same amount of overall change, though it was distributed differently through the classes. The combined 1970's-90's image had a higher amount of total change, and the influence of clouds in the 1984 imagery was not present. Overall, the highest change class was Open to water/wetlands, which was primarily detected in the 1970's-80's image.

To highlight landscape changes only, the Cloud/shadow class was combined with the No change class. The 26 remaining change classes were combined to form three broad ecological change types: Progressive change (that which tends toward succession), Regressive change (that which tends toward disturbance), and Land/water interface change. When the change maps were overlaid with the study area subregions (Table 4.5), it was observed that overall change was highest in the WRG, primarily due to land/water changes. Land/water change was the greatest type of change for each of the other study area subsets as well. However, the amount of Progressive and Regressive change was much lower in the WRG than in the other subsets, and within the WRG, there was more progressive change than regressive.

Table 4.4. Land cover change results within the study area for three change maps (Ag = Agriculture; For = Forest; Shrub = Shrub/grass; Sub = Suburban; W/wet = Water/wetlands).

Change type	1970's-1980's change (ha)	% of study area	% of change area	1980's-1990's change (ha)	% of study area	% of change area	1970's-1990's change (ha)	% of study area	% of change area
No Change	173714.6	98.0	-	173695.0	98.0	-	173201.5	97.7	-
Cloud/shadow	1247.3	0.7	-	1336.5	0.8	-	0.0	0.0	-
Ag to Built	80.0	0.0	3.6	154.1	0.1	7.1	232.5	0.1	5.8
Ag to For	97.4	0.1	4.3	50.2	0.0	2.3	137.9	0.1	3.4
Ag to Shrub	21.9	0.0	1.0	302.0	0.2	13.8	357.7	0.2	8.9
Ag to Sub	34.7	0.0	1.5	32.4	0.0	1.5	73.7	0.0	1.8
Ag to W/wet	280.6	0.2	12.5	109.5	0.1	5.0	316.5	0.2	7.9
For to Ag	135.1	0.1	6.0	62.3	0.0	2.9	172.6	0.1	4.3
For to Built	13.2	0.0	0.6	13.9	0.0	0.6	28.6	0.0	0.7
For to Shrub	39.8	0.0	1.8	161.8	0.1	7.4	209.6	0.1	5.2
For to Sub	13.5	0.0	0.6	18.6	0.0	0.9	29.7	0.0	0.7
For to W/wet	137.4	0.1	6.1	25.5	0.0	1.2	141.1	0.1	3.5
Open to For	6.0	0.0	0.3	2.7	0.0	0.1	15.2	0.0	0.4
Open to Shrub	1.1	0.0	0.1	50.9	0.0	2.3	129.1	0.1	3.2
Open to Sub	13.7	0.0	0.6	61.0	0.0	2.8	69.3	0.0	1.7
Open to W/wet	769.2	0.4	34.2	144.9	0.1	6.6	755.8	0.4	18.8
Shrub to Ag	23.4	0.0	1.0	57.0	0.0	2.6	77.7	0.0	1.9
Shrub to Built	1.1	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0
Shrub to For	104.6	0.1	4.6	180.2	0.1	8.3	258.5	0.1	6.4
Shrub to Sub	0.6	0.0	0.0	1.3	0.0	0.1	1.9	0.0	0.0
Shrub to W/wet	4.6	0.0	0.2	4.8	0.0	0.2	8.3	0.0	0.2
Sub to Built	29.0	0.0	1.3	68.1	0.0	3.1	92.8	0.1	2.3
W/wet to Ag	300.3	0.2	13.3	142.8	0.1	6.5	390.0	0.2	9.7
W/wet to Built	32.7	0.0	1.5	40.4	0.0	1.9	63.2	0.0	1.6
W/wet to For	63.9	0.0	2.8	69.3	0.0	3.2	116.9	0.1	2.9
W/wet to Open	3.3	0.0	0.1	11.3	0.0	0.5	8.5	0.0	0.2
W/wet to Shrub	18.2	0.0	0.8	415.6	0.2	19.0	298.2	0.2	7.4
W/wet to Sub	26.4	0.0	1.2	1.3	0.0	0.1	25.4	0.0	0.6
Total	177213.5	100.0	100.0	177213.5	100.0	100.0	177213.5	100.0	100.0

Table 4.5. Land cover change results (1970's-90's) grouped by study area subset (Ag = Agriculture; For = Forest; Shrub = Shrub/grass; Sub = Suburban; W/wet = Water/wetlands).

Change type	Change class	WRG	% of change	Buffer	% of change	Tributaries	% of change	Floodplain	% of change
Regressive									
	Ag to Built	19.8	1.2	41.7	5.9	57.2	6.3	113.3	14.1
	Ag to Sub	4.8	0.3	19.1	2.7	25.0	2.7	24.8	3.1
	For to Ag	35.6	2.3	30.3	4.3	67.9	7.4	38.3	4.8
	For to Built	8.7	0.6	2.5	0.3	7.0	0.8	10.4	1.3
	For to Shrub	33.3	2.1	74.5	10.5	96.4	10.5	5.4	0.7
	For to Sub	3.5	0.2	2.4	0.3	18.5	2.0	5.5	0.7
	Shrub to Ag	20.3	1.3	38.5	5.4	9.3	1.0	9.6	1.2
	Shrub to Built	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.1
	Shrub to Sub	0.3	0.0	1.7	0.2	0.0	0.0	0.0	0.0
	Sub to Built	20.4	1.3	31.7	4.5	12.7	1.4	28.2	3.5
	Subtotal	146.7	9.3	242.3	34.2	294.1	32.2	236.7	29.4
Progressive									
	Ag to For	15.4	1.0	35.4	5.0	33.0	3.6	54.0	6.7
	Ag to Shrub	58.0	3.7	84.3	11.9	63.6	7.0	151.3	18.8
	Open to For	9.5	0.6	0.6	0.1	2.5	0.3	2.7	0.3
	Open to Shrub	94.0	5.9	14.6	2.1	14.5	1.6	6.3	0.8
	Open to Sub	11.9	0.8	25.1	3.5	12.0	1.3	19.9	2.5
	Shrub to For	71.5	4.5	36.3	5.1	118.7	13.0	31.2	3.9
	Subtotal	260.3	16.4	196.4	27.7	244.2	26.7	265.4	33.0
Land/water									
	Ag to W/Wet	110.3	7.0	85.6	12.1	28.7	3.1	91.8	11.4
	For to W/Wet	98.9	6.2	5.7	0.8	32.3	3.5	4.1	0.5
	Open to W/Wet	481.0	30.4	79.5	11.2	129.1	14.1	66.6	8.3
	Shrub to W/Wet	2.1	0.1	3.5	0.5	2.2	0.2	0.5	0.1
	W/Wet to Ag	157.1	9.9	61.6	8.7	72.1	7.9	99.3	12.3
	W/Wet to Built	43.2	2.7	8.0	1.1	3.8	0.4	8.4	1.0
	W/Wet to For	63.7	4.0	6.5	0.9	46.7	5.1	0.3	0.0
	W/Wet to Open	6.6	0.4	0.0	0.0	1.9	0.2	0.0	0.0
	W/Wet to Shrub	196.3	12.4	19.6	2.8	56.3	6.2	26.2	3.3
	W/Wet to Sub	16.8	1.1	0.0	0.0	3.0	0.3	5.6	0.7
	Subtotal	1176.1	74.3	270.0	38.1	376.0	41.1	302.8	37.6
	Total	1583.0	100.0	708.7	100.0	914.3	100.0	804.9	100.0

The accuracy assessment at the individual class level demonstrated that there was significant confusion between the Agriculture, Shrub/grass, and Suburban classes. For this reason, the reporting of error was collapsed to reflect the four broad ecological classes of change (Congalton 1991). At this level of assessment, the change detection method reports an overall 1970's-90's error of 53.6% (Table 4.6).

DISCUSSION

Landscape change along the Willamette River

The results of this study might suggest that the landscape remained largely static between 1976 and 1995, since 98% of the landscape was labeled as No Change. However, the study area is predominantly (60%) agricultural, and there was indeed a significant amount of intra-class change. The image differencing step captured a great deal of spectral dynamics among the different dates, yet when the expert classifier analyzed this change, most of it was found to be variation among agricultural fields. The seemingly minor amount of change reported in Table 4.4 retains the inter-class change, which is of special interest because it reflects the trend of land use conversion associated with agricultural expansion, gravel mining, urbanization, and river channel change.

Of these, the most abundant was Land/water change, especially within the WRG (Table 4.5). Water level differences, river channel migration, and pond creation (due to aggregate mining), were captured exceedingly well. In addition, some of the detected change resulted from the increased spatial resolution of TM data relative to MSS. The MSS data from 1976 and 1977 had vague boundaries along land/water margins. When compared to the more spatially specific TM data from 1984 and 1988, a substantial element of water to land change appears as a ribbon along the river margins. In addition, the 1984 template 3 and 4 images were acquired in mid-June, compared to mid-August for the 1995 images. This difference was evidenced by a

Table 4.6. Accuracy assessment of a) 1970's-1980's change map; b) 1980's-1990's change map; and c) 1970's-1990's change map.

a) Reference	Map Prediction: No change	Progressive change	Regressive change	Land/water change	Total	%
No change	33	3	4	5	45	73.3
Progressive change	2			1	3	0.0
Regressive change	2	1			3	0.0
Land/water change	2		1	14	17	82.4
Other				1	1	0.0
Total	39	4	5	21	69	68.1

b) Reference	Map Prediction: No change	Regressive change	Progressive change	Land/water change	Total	%
No change	30	6	8	5	49	61.2
Progressive change	5	2	1		8	25.0
Regressive change	2	1	7	3	13	53.8
Land/water change	1	1		5	7	71.4
Other	1		1	1	3	0.0
Total	39	10	17	14	80	55.0

c) Reference	Map Prediction: No change	Regressive change	Progressive change	Land/water change	Total	%
No change	36	12	7	6	61	59.0
Progressive change	8	1	3	1	13	7.7
Regressive change	8	2	3	1	14	21.4
Land/water change	6			11	17	64.7
Other	1		3	1	5	0.0
Total	59	15	16	20	110	46.4

large detection of Water/wetlands to Agriculture and Shrub/grass, due to the fields and wetlands drying out during the Willamette Valley summer.

Of more particular interest for ecologists are the progressive and regressive landscape-scale changes, which indicate important shifts in wildlife habitat, non-point source water pollution, and general ecological decline (Gutowsky 2000). Much of the study area was in a state of dynamic stasis during this time period, with relatively equal amounts of progressive and regressive change balancing each other through the cycles of disturbance and regrowth. In the WRG, however, it appears that there was less forest loss and more agricultural abandonment (some of this was due to acquisition of farmlands for wildlife refuges), creating a net ecological progression.

Loss of riparian vegetation was the particular concern of Frenkel et al. (1984), who reported an aggregated vegetation loss of 294 hectares within the WRG in Benton and Linn counties (17.7% of the WRG) between 1972 and 1981. My study did not detect a comparable amount of change (Table 4.7). There are several reasons for this. Primarily, perhaps, is that satellite remote sensing methods are not as accurate as change detection from aerial photography, since the spatial resolution of photography is better and the interpretation skill of a trained analyst are superior to digital classification methods. Comparisons between the two studies are difficult, since the minimum mapping units of the two studies are different, and the methods and classification schemes are different. And in addition, there was a significant time gap between the two studies; between the time that Frenkel et al. (1984) began their study (1972) and the first acquisition of my satellite imagery (1976), many farmers cleared forests in anticipation of the regulations of the WRG going into effect (Bauer 1980).

Change detection methods

My approach to change detection was to use an expert classifier to combine the spectral information from image differencing with the power of a supervised classification aided by related spectral and land use/land cover data sets. Because

Table 4.7. Comparison of Landsat-derived change with an earlier study which used aerial photography as reference (Frenkel et al. 1984).

		Air photo change (1972-1981)		Remote sensing change (1976-1984)			
County	**Change class**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Difference**	**%**
Benton							
	No-change	2051.4	92.1	2363.7	99.3	312.3	15.2
	For/Shrub to Ag	149.7	6.7	8.6	0.4	-141.2	-94.3
	For/Shrub to Open	26.7	1.2	7.0	0.3	-19.8	-74.0
	For/Shrub to Sub/Built	0.0	0.0	0.0	0.0	0.0	-
	Subtotal	2227.9	100.0	2379.3	100.0	151.4	6.8
Linn							
	No-change	2840.2	96.0	2729.2	99.5	-111.0	-3.9
	For/Shrub to Ag	79.7	2.7	3.5	0.1	-76.2	-95.6
	For/Shrub to Open	24.3	0.8	10.9	0.4	-13.4	-55.2
	For/Shrub to Sub/Built	13.4	0.5	0.6	0.0	-12.8	-95.6
	Subtotal	2957.5	100.0	2744.2	100.0	-213.3	-7.2
Total							
	No-change	4891.6	94.3	5093.0	99.4	201.4	4.1
	For/Shrub to Ag	229.5	4.4	12.1	0.2	-217.4	-94.7
	For/Shrub to Open	51.0	1.0	17.8	0.3	-33.2	-65.0
	For/Shrub to Sub/Built	13.4	0.3	0.6	0.0	-12.8	-95.6
	Total	5185.4	100.0	5123.5	100.0	-61.9	-1.2

change detection was the primary goal, the routine only classified pixels that had changed spectrally between the image dates. It is possible that certain land cover change types (e.g. Agriculture to Shrub/grass) went undetected because their spectral signals were too similar to detect in image differencing. However, for those pixels that were significantly different between dates, the expert classifier worked well to label them as either No change or one of 27 different change vectors. In particular, the expert classifier allowed me to apply certain assumptions about land cover based on the three ancillary land use/land cover data sets. It was only through these assumptions that the spectral confusion between Agriculture, Shrub/grass, and Suburban classes was minimized, based on the location of a pixel relative to zoning designations and land cover maps generated either by aerial photography or a multi-seasonal TM data set. The fact that the Land/water change was well detected is a direct result of the unique spectral properties of water, compared to the diversity of spectral signatures associated with inter-class training polygons.

The change maps were improved using a minimal amount of hand-editing to correct known misclassifications, especially those due to inaccuracies in the land use/land cover GIS layers. To construct the best possible map, other more-detailed corrections could be accomplished, for example using the full photo reference to verify each change polygon. In such a case, the automated remote sensing method would highlight pixels to examine further in photography. Another improvement would be the addition of multi-temporal Landsat imagery to help distinguish the seasonal variation of agricultural fields and separate them from natural shrub/grass, suburb, and other similar classes (Oetter et al. 2001).

These land cover change maps represent a quick and straightforward approach for obtaining reliable results in a dynamic environment using Landsat imagery. The question remains as to whether Landsat imagery is good enough to compare with an aerial photography approach. Many studies have used photography to detect change along rivers, since it offers excellent resolution of both land cover and land use, within the abilities of the photo interpreter. Especially for detailed vegetation riparian change studies, where species composition and structure are important (Johnson 1994; Dixon and Carter 1999; Moser et al. In press), the fine scale and discernment of human interpretation of air photos is desirable (Rowlinson et al. 1999; Congalton et al. 2000).

However, the physical and temporal costs of acquiring and interpreting air photos can be prohibitive over large areas (Muller 1997); a study comparable to mine (177 km^2 over 300 river km) could require thousands of hours of skilled labor to interpret, transfer, and digitize and georegister change polygons into a usable GIS coverage (Allen 1999). Assuming that training in GIS and remote sensing methods is not a significant constraint (Harris et al. 1997), there are many distinct advantages to using satellite imagery (Lehmann and Lachavanne 1997). Among these are the relatively inexpensive availability of imagery across a large area, the spectral information contained in infrared bands for vegetation analysis, and the ability to integrate imagery with ancillary GIS data (Hewitt 1990; Lee and Marsh 1995; McLeod and Congalton 1998; Iverson et al. 2001; Kovacs et al. 2001). In the absence of complete photo coverage, satellite imagery analyzed in one location can be extrapolated across a much larger landscape (Muchoney and Haack 1994). In addition, remotely sensed data are ideally suited for expert classification routines using ancillary GIS information (Janssen and Middelkoop 1992; Ehrlich et al. 1994; Narumalani et al. 1997), and having the change data in digital format offers many advantages for later analysis (Muller 1997). At regional scales, the results of remotely sensed land cover estimates have proven useful for predicting landscape-scale ecological processes (Wickham et al. 1997; Lattin et al. In press).

The problems with my approach were discovered during the accuracy assessment phase, as the differences between land cover classification from satellite imagery and aerial photography became evident. In addition to a wide range of misregistration issues, especially from the MSS to TM comparison, the change maps were in error when compared to higher-resolution photos that could be interpreted with some knowledge of the general setting. For example, a pasture can be labeled as Agriculture from a photograph, as the use of the land is evident from feeding stations, cattle trails, and such, but in a TM image that same cover type might resemble a grass field, a natural grassland, or even a public park, depending on its condition at the time of capture. A significant amount of information is lost due to spectral confusion of the MSS and TM pixels. Pixels along the edges of land cover units have mixed signatures and are difficult to classify as only one cover class (Metzger and Muller 1996). Many of these pixels were removed from the final map by a filtering routine with a minimum mapping unit of four contiguous pixels (0.25 ha). Higher resolution satellite imagery (e.g., IKONOS) may improve the change detection, but at the added cost of image acquisition and image processing costs. The Willamette Valley is a very diverse landscape with a high degree of ecological edge (Oetter et al. 2001; Hulse et al. 2002), which can further confound classification of pixels containing multiple land covers. Whereas the error assessment point might be clearly determined when viewed atop the digitized and orthorectified photo reference, its position along a fuzzy edge in the TM imagery could make the classification fail. In addition, the differences in acquisition date highlighted classification error; it would be ideal to acquire reference photography from the same year (or month) as the satellite imagery, but this was not the case in this study. This problem was compounded for water and wetlands, as the seasonal fluctuation of water levels may not have coincided in both imagery and the photos.

Summary

This research has outlined a reliable and efficient method for detecting change in a diverse landscape along a linear feature. The methodology relies on image differencing to capture spectral changes in Landsat data, which can be classified using an expert classifier to determine the directions of change. For a trained analyst using modern digital processing software, the method should be cheaper and quicker to use than air photo interpretation, especially over a large area. Having been developed for a highly diverse environment, the method is applicable to many other locations depending on the scale of landscape change to be detected. In many cases, the method can be improved either by adding information from reference photography or using improved ancillary GIS layers to better interpret the environment.

In this particular case, the main objective was to describe recent change along the WRG, as an update to work completed earlier which indicated that natural land cover was being displaced by agriculture and development (Frenkel et al. 1984). Examining a greater area over a longer time frame, I could not conclude that natural vegetation loss within the WRG is still occurring at a rate greater than the surrounding landscape. In fact, the greatest amount of change within the WRG appears to be coming from Land/water interactions associated with river channel change and wetlands fluctuations. And in any event, the greatest amount of change along the river likely occurred about 100 years ago (Hulse et al. 2002), during a period of high forest removal. A future research direction is a more in-depth analysis of the scale of ecological change along the Willamette River, both before and after the institution of the WRG.

A secondary objective was to test the suitability of Landsat data for detecting change. Given the large extent of the study area, the remote sensing approach was a prudent methodology, especially with a historical change study where complete, intact aerial photography may not be consistently available for the full region. The remote sensing approach has its limitations, however, and it may be that its real advantage is at the landscape level, where misclassification can be averaged across larger land units. A high degree of ecological edge in an agricultural, forested, and developed setting along a major linear water feature brings out the worst in remotely sensed cover change products (Metzger and Muller 1996). However, it is often the edge that is of the most importance.

ACKNOWLEDGEMENTS

This research would not have been possible without the kind support of A. Jon Kimerling, Warren B. Cohen, Robert E. Frenkel, and Stanley V. Gregory of Oregon State University. Additionally, Thomas K. Maiersperger, Sara R. Lipow, and

Linda R. Ashkenas offered considerable technical knowledge, editorial assistance, and general aid. The Pacific Northwest Ecosystem Research Consortium (http://www.orst.edu/dept/pnw-erc/) provided invaluable technical support and advice.

REFERENCES

Allan, J. D., and A. S. Flecker, 1993. Biodiversity conservation in running waters. BioScience, 43(1):32-43.

Allen, T. H., 1999. Areal distribution, change, and restoration potential of wetlands within the lower Columbia River riparian zone, 1948-1991, Ph.D. dissertation, Department of Geosciences, Oregon State University, Corvallis, 280 pp.

Bauer, W. S., 1980. A Case Analysis of Oregon's Willamette River Greenway Program, Ph.D. dissertation, Department of Geography, Oregon State University, Corvallis, 246 pp.

Bayley, P. B., 1995. Understanding large river-floodplain ecosystems, BioScience, 45(3):153-158.

Benner, P. A., and J. R. Sedell, 1997. Upper Willamette River landscape: a historic perspective, River quality: dynamics and restoration (Laenen, A., and D. A. Dunnette, editors), Lewis Publishers, Boca Raton, pp. 23-47.

Boon, P. J., P. Calow, and G. E. Petts, 1992. River Conservation and Management, John Wiley & Sons, Chichester, 470 pp.

Cohen, W. B., and M. Fiorella, 1998. Comparison of methods for detecting conifer forest change with Thematic Mapper imagery, Remote Sensing Change Detection: Environmental Monitoring Methods and Applications, (Lunetta, R. S., and C. D. Elvidge, editors), Ann Arbor Press, Chelsea, Michigan, pp. 89-102.

Cohen, W. B., T. K. Maiersperger, T. A. Spies, and D. R. Oetter, 2001. Modeling forest cover attributes as continuous variables in a regional context with Thematic Mapper data, International Journal of Remote Sensing, 22(12):2279-2310.

Collins, J. B., and C. E. Woodcock, 1994. Change detection using the Gramm-Schmidt transformation applied to mapping forest mortality, Remote Sensing of Environment, 50(3):267-279.

Congalton, R. G., K. Birch, R. Jones, J. Powell, and J. R. Schriever, 2000. Evaluating remotely sensed techniques for mapping riparian vegetation, Second International Conference on Geospatial Information in Agriculture and Forestry, 10-12 Jan., Lake Buena Vista, Florida, pp. I-77-86.

Crist, E. P., and R. C. Cicone, 1984. Physically-based transformation of Thematic Mapper data- the TM Tasseled Cap, IEEE Transactions on Geoscience and Remote Sensing, GE-22:256-263.

Dykaar, B. B., and P. J. Jr. Wigington, 2000. Floodplain formation and cottonwood colonization patterns on the Willamette River, Oregon, USA, Environmental Management, 25(1):87-104.

Décamps, H., 1993. River margins and environmental change, Ecological Applications, 3(3):441-45.

Dixon, M. D., and W. C. Johnson, 1999. Riparian vegetation along the middle Snake River, Idaho: zonation, geographical trends, and historical changes, Great Basin Naturalist, 59(1):18-34.

Ehrlich, D., J. E. Estes, J. Scepan, and K. C. McGwire, 1994. Crop area monitoring with an advanced agricultural information system, Geocarto International, 9(4):31-42.

ERDAS, 2002. ERDAS Imagine Expert Classifier, ERDAS, Inc, Atlanta, Georgia, 29 pp.

Frenkel, R. E., S. V. Gregory, and J. R. Sedell, 1991. The Willamette River: an ecosystem in need of a new vision. Oregon State University, Corvallis, Oregon, unpublished.

Frenkel, R. E., S. N. Wickramaratne, and E. F. Heinitz, 1984. Vegetation and land cover change in the Willamette River Greenway in Benton and Linn Counties, Oregon: 1972-1981, Association of Pacific Coast Geographers Yearbook, 46:63-77.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley, 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context, Environmental Management, 10(2):199-214.

Fung, T., and E. LeDrew, 1988. The determination of optimal threshold levels for change detection using various accuracy indices, Photogrammetric Engineering & Remote Sensing, 54(10):1449-1454.

Gardiner, John L., 1999. Willamette River floodplain restoration study: section 905(b) reconnaissance report. Report prepared for U. S. Army Corps of Engineers, Philip Williams & Associates, Portland, Oregon, 40 pp.

Gleeson, George W., 1972. The Return of a River: The Willamette River, Oregon, Water Resources Research Institute, Oregon State University, Corvallis, Oregon, 103 pp.

Graf, W. L., 2001. Damage control: restoring the physical integrity of America's rivers, Annals of the Association of American Geographers, 91(1):1-27.

Gregory, S., D. Landers, L. Ashkenas , R. Wildman, P. Minear, D. Oetter , P. Bayley, C. Andrus, M. Pearson , and S. Fernald, In preparation. Historical and future trajectories of floodplains, forests, and off-channel habitats of the mainstem Willamette River, Ecological Applications.

Gregory, S. V., 1999. Ecological, demographic, and economic evaluation of opportunities and constraints for riparian restoration, Oregon State University, Corvallis, Oregon, unpublished.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins, 1991. An ecosystem perspective of riparian zones, BioScience, 41(8):540-51.

Gurnell, A. M., 1997. The hydrological and geomorphological significance of forested floodplains, Global Ecology and Biogeography Letters, 6(3/4):219-229.

Gutowsky, S. L., 2000. Riparian cover changes associated with flow regulation and bank stabilization along the Upper Willamette River in Oregon between 1939 and 1996, Master's Thesis, Department of Geosciences, Oregon State University, Corvallis, Oregon, 92 pp.

Harris, R. R., P. Hopkinson, S. McCaffrey, and L. Huntsinger, 1997. Comparison of a Geographical Information System versus manual techniques for land cover analysis in a riparian restoration project, Journal of Soil and Water Conservation, 52(2):112-117.

Hayes, D. J., and S. A. Sader, 2001. Comparison of change-detection techniques for monitoring tropical forest clearing and vegetation regrowth in a time series, Photogrammetric Engineering & Remote Sensing, 67(9):1067-1075.

Hewitt III, M. J., 1990. Synoptic inventory of riparian ecosystems: The utility of Landsat Thematic Mapper data, Forest Ecology and Management, 33/34:605-620.

Honey Jr., William D., 1975. The Willamette River Greenway: Cultural and Environmental Interplay. Water Resources Research Institute, Corvallis, Oregon, 133 pp.

Hulse, D., S. Gregory, and J. Baker (eds.), 2002. Willamette River Basin: A Planning Atlas, Oregon State University Press, Corvallis, Oregon 178 pp.

Hupp, C. R., and W. R. Osterkamp, 1985. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms, Ecology, 66(3):670-681.

Iverson, L. R., D. L. Szafoni, S. E. Baum, and E. A. Cook, 2001. A riparian wildlife habitat evaluation scheme developed using GIS, Environmental Management, 28(5):639-654.

Janssen, L. L. F., and H. Middelkoop, 1992. Knowledge-based crop classification of a Landsat Thematic Mapper image, International Journal of Remote Sensing, 13(15):2827-2837.

Jensen, J. R., K. Rutchey, M. S. Koch, and S. Narumalani, 1995. Inland wetland change detection in the Everglades water conservation Area 2A using a time series of normalized remotely sensed data, Photogrammetric Engineering & Remote Sensing, 61(2):199-209.

Johnson, W. C., 1997. Equilibrium response of riparian vegetation to flow regulation in the Platte River, Nebraska, Regulated Rivers: Research & Management, 13(5):403-415.

Kauth, R. J., and G. S. Thomas, 1976. The Tasseled Cap- a graphic description of the spectra-temporal development of agricultural crops as seen by Landsat, Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, Date, Purdue University, City, Indiana, pp. 41-51.

Kleiman, R. E., and D. L. Erickson, 1996. Landscape change in an agricultural watershed: the effect of parcelization on riparian forest cover, Environment and Planning B: Planning and Design, 23(1):25-36.

Kovacs, J. M., J. Wang, and M. Blanco-Correa, 2001. Mapping disturbances in a mangrove forest using multi-date Landsat TM imagery, Environmental Management, 27(5):763-776.

Lattin, P. D., P. J. Wigington Jr., B. E. Peniston, D. R. Lindeman, D. R. Oetter, and T. J. Moser, In press. Riparian land cover-land use and stream ecological conditions: a comparison of data derived from aerial photography and Landsat Thematic Mapper imagery, Journal of the American Water Resources Association.

Lee, C. T., and S. E. Marsh, 1995. The use of archival Landsat MSS and ancillary data in a GIS environment to map historical change in an urban riparian habitat, Photogrammetric Engineering & Remote Sensing, 61(8):999-1008.

Lee, K. H., and R. S. Lunetta, 1995. Wetlands detection methods, Wetland and Environmental Applications of GIS, (Lyon, J. G., and J. McCarthy, editors), Lewis Publishers, Boca Raton, Florida, pp. 249-284.

Lehmann, A., and J.-B. Lachavanne, 1997. Geographic information systems and remote sensing in aquatic botany, Aquatic Botany, 58(3-4):195-207.

Leland, D., S. Anderson, and D. J. Sterling Jr., 1997. The Willamette- a river in peril, Journal of the American Water Works Association, 89(11):73-83.

Little, C. E., 1990. Greenways for America, The Johns Hopkins University Press, Baltimore, 237 pp.

Llewellyn, D. W., G. P. Shaffer, N. J. Craig, L. Creasman, D. Pashley, M. Swan, and C. Brown, 1996. A decision-support system for prioritizing restoration sites on the Mississippi River alluvial plain, Conservation Biology, 10(5):1446-1455.

Macleod, R. D., and R. G. Congalton, 1998. A quantitative comparison of change-detection algorithms for monitoring eelgrass from remotely sensed data, Photogrammetric Engineering & Remote Sensing, 64(3):207-216.

Malanson, G. P., 1993. Riparian Landscapes, Cambridge University Press, New York, 296 pp.

Metzger, J. P., and E. Muller, 1996. Characterizing the complexity of landscape boundaries by remote sensing, Landscape Ecology, 11(2):65-77.

Michener, W. K., and P. F. Houhoulis, 1997. Detection of vegetation changes associated with extensive flooding in a forested ecosystem, Photogrammetric Engineering & Remote Sensing, 63(12):1363-1374.

Milton, E. J., D. J. Gilvear, and I. D. Hooper, 1995. Investigating change in fluvial systems using remotely sensed data, Changing River Channels, (Gurnell, A., and G. Petts, editors), John Wiley & Sons, Chichester, pp. 277-301.

Moser, T. J., D. R. Lindeman, P. J. Wigington Jr., M. J. Schuft, and J. Van Sickle, 2000. Methods for multi-spatial scale characterization of riparian corridors, Proceedings International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds, 28-31 August, Portland, Oregon, (American Water Resources Association, Middleburg, Virginia), pp. 511-516.

Muchoney, D. M., and B. N. Haack, 1994. Change detection for monitoring forest defoliation, Photogrammetric Engineering & Remote Sensing, 60(10):1243-1251.

Muckleston, K. W., 1986. The changing uses of the Willamette River, Beitrage zur Hydrologie, 6(Kirchzarten):41-57.

Muller, E., 1997. Mapping riparian vegetation along rivers: old concepts and new methods, Aquatic Botany, 58(3-4):411-437.

Muller, E., H. Décamps, and M. K. Dobson, 1993. Contribution of space remote sensing to river studies, Freshwater Biology, 29(2):301-312.

Naiman, R. J., H. Décamps, J. Pastor, and C. A. Johnston, 1988. The potential importance of boundaries to fluvial ecosystems, Journal of the North American Benthological Society, 7(4):289-306.

Naiman, R. J., H. Décamps, and M. Pollock, 1993. The role of riparian corridors in maintaining regional biodiversity, Ecological Applications, 3(2):209-12.

Narumalani, S., Y. Zhou, and J. R. Jensen, 1997. Application of remote sensing and geographic information systems to the delineation and analysis of riparian buffer zones, Aquatic Botany, 58(3-4):393-409.

[NRC-CRAE] National Research Council Committee on Restoration of Aquatic Ecosystems- Science, Technology and Public Policy, 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy, National Academy Press, Washington, D. C., 552 pp.

Neale, C. M. U., 1997. Classification and mapping of riparian systems using airborne multispectral videography, Restoration Ecology, 5(4S):103-112.

Oetter, D. R., L. R. Ashkenas, S. V. Gregory, and P. J. Minear, In review. GIS methodology for characterizing historical conditions of the Willamette River floodplain, Oregon, Transactions in GIS.

Oetter, D. R., W. B. Cohen, M. Berterretche, T. K. Maiersperger, and R. E. Kennedy, 2001. Land cover mapping in an agricultural setting using multi-seasonal Thematic Mapper data, Remote Sensing of Environment, 76(2):139-155.

[OSPRB] Oregon State Parks and Recreation Branch, Department of Transportation, 1976. A Proposal for the Willamette River Greenway, Oregon State Parks and Recreation Branch, Department of Transportation, Salem, Oregon, 4 vol.

Russell, G. D., C. P. Hawkins, and M. P. O'Neill, 1997. The role of GIS in selecting sites for riparian restoration based on hydrology and land use, Restoration Ecology, 5(4S):56-68.

San Miguel-Ayanz, J., and G. S. Biging, 1997. Comparison of single-stage and multi-stage classification approaches for cover type mapping with TM and SPOT data, Remote Sensing of Environment, 59(1):92-104.

Sedell, J. R., and J. L. Froggatt, 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U. S. A., from its floodplain by snagging and streamside forest removal, Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie, 22:1828-34.

Smith, D. S., and P. C. Hellmund, 1993. Ecology of Greenways: Design and Function of Linear Conservation Areas, University of Minnesota Press, Minneapolis, 222 pp.

Starbird, E. A., 1972. A river restored: Oregon's Willamette, National Geographic, 141:816-835.

Ward, J. V., and J. A. Stanford, 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation, Regulated Rivers, 11(1):105-119.

Weber, R. M., and G. A. Dunno, 2001. Riparian vegetation mapping and image processing techniques, Hopi Indian Reservation, Arizona, Photogrammetric Engineering & Remote Sensing, 67(2):179-186.

Wickham, J. D., R. V. O'Neill, K. H. Riitters, T. G. Wade, and K. B. Jones, 1997. Sensitivity of selected landscape pattern metrics to land-cover misclassification and differences in land-cover composition, Photogrammetric Engineering & Remote Sensing, 63(4):397-402.

Wickware, G. M., and P. J. Howarth, 1981. Change detection in the Peace-Athabasca delta using digital Landsat data, Remote Sensing of Environment, 11(1):9-25.

Willamette Restoration Initiative, 2001. Restoring a River of Life: The Willamette Restoration Strategy Overview, Willamette Restoration Initiative, Salem, Oregon, 26 pp.

Willamette Riverkeeper, 2002. Willamette Riverkeeper, URL: http://www.willamette-riverkeeper.org/, Willamette Riverkeeper, Portland, Oregon, (last date accessed 3 November 2002).

CHAPTER 5

SUMMARY AND CONCLUSION

SUMMARY OF FINDINGS

The overall goal of this thesis was to characterize landscape change along the Willamette River. This goal was met using three different approaches, each employing a variety of geographical techniques to model landscape conditions.

Chapter 2 outlined a methodology for converting historic and present data into spatial data layers which characterize floodplain conditions. Using early surveyor records, historic maps, and modern remote sensing techiques, detailed estimates were made of historic and current river channel locations, floodplain extents, and riparian land cover. While previous studies have achieved similar results, this is one of the first major research efforts to characterize the entire floodplain for a large mainstream river. The results of this analysis are reported in the *Willamette River Basin Planning Atlas* (PNWERC 2002) as well as a special issue of *Ecological Applications* (Gregory et al. in review). This work provides much of the necessary input to a spatial model that ranks potential floodplain restoration sites as part of a major interagency effort to restore the Willamette River floodplain.

Chapter 2 findings include:

- A GIS is an efficient method for characterizing historical river and riparian conditions from a variety of data sources;
- Channel complexity has been reduced over time, more in the upper reach;
- Floodplain forest has been dramatically diminished in all reaches;
- The results can be used both to describe the changes that have occurred and to help locate specific floodplain locations for restoration.

Chapter 3 detailed a useful methodology for mapping agricultural landscapes using a relatively undiscovered ground reference data set (Farm Service Agency slides) combined with a powerful spectral approach to classifying remote sensor data (Tasseled Cap transformation). The multi-seasonal methodology developed here would be useful in almost any land cover mapping effort, but especially in one dominated by a variety of agricultural cover types. The resulting map of the Willamette Valley was combined with pre-exisiting work (Cohen et al. 2001) to produce an accurate high-resolution land cover map of the Willamette River Basin that has been used by dozens of researchers and policy makers.

Conclusions from Chapter 3 include:

- Farm Service Agency crop compliance slides represent a h igh-resolution year-to-year reference data set in a large scale and with specific usefulness to agricultural cover types;
- Multi-temporal satellite data allow detailed mapping of 20 agricultural land cover types, especially through the association of the Tasseled Cap greenness index with seasonal crop patterns;
- Analysis of known land cover types in multi-temporal feature space allows greater separation of non-agricultural land cover types, because spectral signals migrate over a growing season.

Chapter 4 focused on evaluating the ability of satellite remote sensing techniques to capture land cover change along a mainstem river. Most similar studies have used extensive air photo analysis, which is costly both in time and expense. Using satellite images I was able to map change in a 1770 km^2 area quicker and cheaper. The study identified lands which underwent land cover change and may be candidate areas for acquisition, restoration, or protection. The overall amount of recent change along the river is much less than what was indicated by Frenkel et al. (1984), and there was less land cover change inside the WRG than along significant tributaries and outside the greenway. The use of satellite remote sensing methods is viable for mapping change across large regions.

Results from Chapter 4 showed that:

- Both MSS and TM imagery portrayed Land/water change;

- TM imagery was more effective for mapping most land cover change, but some change types were confused (esp. among agriculture, shrub/grass, and suburb);
- Use of an expert classifier improved the classification by adding ancillary GIS coverages to clarify land use types;
- While the total area of change was highest within the WRG, 75% of this change was associated with Land/water interaction, and only 9% was associated with Regressive change. For the other three subregions, Regressive change was much higher (34% in the Buffer, 32% in the Tributaries and 29% in the Floodplain);
- This method did not detect as much change as Frenkel et al. (1984), both because of the resolution of satellite imagery and also because the two studies were conducted at different dates, and there may not have been as much change in the later time period of the remote sensing study.

In summary, the remote sensing and GIS methods developed here effectively characterized historical and present land cover along the Willamette River. There are, of course, many problems with employing these methods. The biggest of these was the use of coarse resolution satellite imagery (resampled to 25m pixel size) to map a complex landscape where much of the riparian forest has been removed to within several feet of the river's edge. In many places, due to misregistration and resolution issues, the satellite imagery was ineffective at detecting riparian vegetation and land cover change. This is partly a function of the highly fragmented landscape along the river as well. To be more accurate, aerial photography would provide a better resolution, however the large spatial extent of this project made that approach unfeasible, and satellite imagery proved a useful alternative. In addition, the GIS approach lends itself readily to numerical analysis and generation of descriptive tables, maps, and graphs.

FUTURE RESEARCH

The data generated in Chapter 4 will be used to analyze the socio-economic influences on land conversion along the river, and to determine the landscape-level effectiveness of the WRG land use planning goal. If Goal #15 is working to preserve the natural, scenic, and historical qualities of the land along the Willamette River, then land use change within the WRG should not exceed that of areas immediately adjacent to the greenway or along major tributaries. A future paper will test that hypothesis and further examine land cover changes along the river, looking for answers to the question of what has driven land cover change in the past.

At the moment, it appears that most of the conversion of riparian forest took place long before the WRG was established, as European settlers removed the forest and channelized the river over 100 years ago (Sedell and Froggatt 1984; Boag 1992; Benner and Sedell 1997; Robbins 1997). But land use conversion is also occurring in modern times, as Frenkel et al. (1984) duely noted. The fear of many conservationists is that the urban areas will continue to expand, converting more of the riparian forest into homes and roadways.

My ideas for researching this trend include using a GIS and logistic regression techniques to analyze the socio-economic characteristics of the lands that have changed, with the notion that land rent is a driving factor in promoting change (Mather 1986; Kline and Alig 1999). I would also employ county and state records of land zoning decisions that allowed development inside the WRG, to get a clearer picture of the actual motivations behind land conversion. Other examples of explanatory variables that could guide a GIS investigation into land cover change include: age, political affiliation, occupation, dwelling type, demographics, newspaper subscription, and access to regional markets. The impetus for land use conversion does not necessarily follow a strict land rent model; other models of irrational consumer behavior may apply. Other historical methods could also be used, including narratives, photographs, and written histories, as I construct a story of how the riverside land changed over time.

In most cases, the imposition of the WRG came well after the major environmental change occurred, and so the development of historical data for small number of case studies could help address current management goals with regard to past conditions (Petts et al. 1989; Frenkel et al. 1991; Raap 1997; WRI 2001). And beyond telling the story of landscape change along the Willamette River, my goal remains to evaluate the effectiveness of the land use planning goal (Goal #15) from a landscape point of view, by measuring how well the land within the WRG has been protected from the current types of changes taking place nearby.

Policy evaluation is a critical phase in adaptive management (CAETEP 1986; FEMAT 1993) and ecological planning (Slocombe 1993). The overall intent of Goal #15 is to protect lands along the Willamette River from land use intensification (OLCDC 1990). While a complete assessment of the implementation of Goal #15 may be unattainable, especially with regard to scenic and historical resources, measuring land use conversion is a reasonable proxy for evaluating the protection of natural and agricultural lands within the WRG. If the current land use control effort is actually working to preserve natural lands along the river, then it might be expanded or otherwise adapted to incorporate additional goals. If it is not working, then more attention can be directed to alternative restoration plans, such as fee simple acquisition or conservation easements (Gardiner 1999; Gregory 1999).

Land cover change may not be the only measure of environmental change that comments on the way that we are developing the Earth, but it certainly is useful for demonstrating actual changes that occur as a result of our actions. The application of remote sensing and GIS technologies should improve our ability to monitor changes that human invoke, as well as allow researchers to identify those changes that are in response to certain public policies. Geographic tools, such as those I used in this study, are available to policy makers and should be used more frequently.

CONCLUSION

I selected this study because I believe that we can learn from our past. There are many cases in environmental history where we can look back on the deeds of our predecessors and see that they were short-sighted; they took actions which damaged the environment, today and for a long, long time. The Willamette River offers us an opportunity not just to analyze the failures of the past, but also to correct their lingering ill effects.

This thesis has demonstrated that since European settlement of the Willamette Valley, the Willamette River has undergone a tremendous amount of human-invoked change. Most of the side channels and islands that were an integral part of the river in 1850 have disappeared, cut off from the main channel by dams and revetments. The extensive bottomland forest that stretched across the pre-settlement floodplain has been removed to make room for farms and urban growth. Most of the land within the historic floodplain is now in agriculture or a built condition; only 27% can still be called semi-natural. And at the same time, the remaining forests along the river are continually being converted to other uses.

The Willamette River represents a difficult natural resource to manage; rivers are fluid in more ways than one as both the physical and social environment changes frequently. My study used remote sensing and GIS techniques to model the land use change along the river, to provide factual scientific information on what has happened historically in this system. My future research aims to go further, to take the technical data generated here and apply it to the socioeconomic questions of land use planning and land cover conversion. Together the technical papers provide collective support for the argument that riparian restoration along the Willamette River is needed, and their data will help us evaluate the WRG's role in maintaining natural qualities along the river.

The academic tradition of resource geography encourages us to take a comprehensive approach to the study of an environmental system. Only then can we make informed decisions about what happened in the past and what should take place in the future. The nature of resource management is uncertainty (Ludwig et al. 1993), so we need the best information available and a sound philosophical approach to help guide our civilization into a more certain future. As scientists, we gather extensive amounts of technical information, but we must go further with it (Shaffer et al. 2002). The role of the scientific community in today's world is to help restore the integrity of the biological and physical systems which support our lives and our economies

(Graf 2001; Large et al. 1992). We must take the lessons of the past and apply them to solve the problems of today.

On a recent summer day along the banks of the Willamette River, I witnessed dozens of men, women, and children playing on the rocky beach. They were skipping stones and just looking out across the water. They were drawn to the river's edge. The shared knowledge of those who study and understand the natural world should impel us all to work to build a lasting natural environment that can continue to provide, purify, and inspire. Rivers should function well not just for their economic benefits, but also for the spiritual and sublime. We need to work to ensure that human civilization develops not at the expense of the natural world, but toward some more ideal future.

BIBLIOGRAPHY

Abbott, Carl, Deborah Howe, and Sy Adler. 1994. *Planning the Oregon way: a twenty-year evaluation.* Corvallis, Oregon: Oregon State University Press.

Adinarayana, J., J. D. Flach, and W. G. Collins. 1994. Mapping land use patterns in a river catchment using geographical information systems. *Journal of Environmental Management* 42(1):55-61.

Alig, Ralph J., and Robert G. Healy. 1987. Urban and built-up land area changes in the United States: an empirical investigation of determinants. *Land Economics* 63(3):215-226.

Allan, J. David, and Alexander S. Flecker. 1993. Biodiversity conservation in running waters. *BioScience* 43(1):32-43.

Allen, Craig D. 1994. Ecological perspective: linking ecology, GIS, and remote sensing to ecosystem management. In *Remote sensing and GIS in ecosystem managment*, ed. V. Alaric Sample, 111-139. Covelo, Calif.: Island Press.

Allen, Tracy Hunter. 1999. Areal distribution, change, and restoration potential of wetlands within the lower Columbia River riparian zone, 1948-1991. Ph.D. dissertation, Department of Geosciences, Oregon State University.

Aspinall, R. 1993. Use of geographic information systems for interpreting land-use policy and modelling effects of land-use change. In *Landscape Ecology and Geographic Information Systems*, eds. Roy H. Haines-Young, David R. Green, and Steven Cousins, 223-236. London: Taylor & Francis.

Auble, Gregor T. 1989. Modeling wetland and riparian vegetation change. Paper presented at Wetlands and River Corridor Management, Berne, NY.

Baker, William L. 1989. A review of models of landscape change. *Landscape Ecology* 2(2):111-133.

Baschak, Lawrence A., and Robert D. Brown. 1995. An ecological framework for the planning, design and management of urban river greenways. *Landscape and Urban Planning* 33:211-225.

Bauer, Marvin E., Marilyn M. Hixson, Barbara J. Davis, and Jeanne B. Etheridge. 1978. Area estimation of crops by digital analysis of Landsat data. *Photogrammetric Engineering & Remote Sensing* 44(8):1033-1043.

Bauer, Webb S. 1980. A Case Analysis of Oregon's Willamette River Greenway Program. Ph.D. dissertation, Department of Geography, Oregon State University.

Baumann, Duane D., and Daniel Dworkin. 1978. *Water Resources for Our Cities.*, *Resource Papers for College Geography*. Washington: Association of American Geographers.

Bayley, Peter B. 1995. Understanding large river-floodplain ecosystems. *BioScience* 45(3):153-158.

Benner, P.A., and Sedell, J.R., 1997. Upper Willamette River landscape: a historic perspective. In *River quality: dynamics and restoration*, eds. A. Laenen and D.A. Dunnette, 23-47. Boca Raton: Lewis Publishers.

Binford, Michael W., and Michael J. Buchenau. 1993. Riparian greenways and water resources. In *Ecology of Greenways: Design and Function of Linear Conservation Areas*, eds. Daniel S. Smith and Paul Cawood Hellmund, 69-104. Minneapolis: University of Minnesota Press.

Boag, Peter G. 1992. Environment and Experience: Settlement Culture in Nineteenth-Century Oregon. Berkeley: University of California Press.

Bockstael, Nancy E. 1996. Modeling economics and ecology: the importance of a spatial perspective. *American Journal of Agricultural Economics* 78:1168-1180.

Bolling, David M. 1994. *How to Save a River: A Handbook for Citizen Action.* Covelo, Calif.: Island Press.

Boon, P. J. 1992. Essential elements in the case for river conservation. In *River conservation and management*, eds. P. J. Boon, P. Calow, and G. E. Petts, 11-33. New York: John Wiley & Sons.

Boon, P. J., Peter Calow, and Geoffrey E. Petts. 1992. *River Conservation and Management*. Chichester: John Wiley & Sons.

Bradshaw, Ted K., and Brian Muller. 1998. Impacts of rapid urban growth on farmland conversion: application of new regional land use policy models and geographic information systems. *Rural Sociology* 63(1):1-25.

Brewster, C. C., J. C. Allen, and D. D. Kopp. 1999. IPM from space: Using satellite imagery to construct regional crop maps for studying crop-insect interaction. *American Entomologist* 45:105-117.

Briassoulis, Helen. 2001. Policy-oriented integrated analysis of land-use change: an analysis of data needs. *Environmental Management* 27(1):1-11.

Brisco, B., and R. J. Brown. 1995. Multidate SAR/TM synergism for crop classification in western Canada. *Photogrammetric Engineering & Remote Sensing* 61(8):1009-1014.

Brookes, Andrew. 1996. River channel change. In *River Flows and Channel Forms*, eds. Geoffrey E. Petts and Peter Calow, 369-388. Oxford: Blackwell Science.

Buechel, Sally W., Warren R. Philipson, and William D. Philpot. 1989. The effects of a complex environment on crop separability with Landsat TM. *Remote Sensing of Environment* 27:261-272.

Bunting, Robert. 1997. *The Pacific raincoast: environment and culture in an American Eden, 1778-1900*. Lawrence: University Press of Kansas.

Carbone, Gregory J., Sunil Narumalani, and Michelle King. 1996. Application of remote sensing and GIS technologies with physiological crop models. *Photogrammetric Engineering & Remote Sensing* 62(2):171-179.

Chauvet, E., and Henri Décamps. 1989. Lateral interactions in a fluvial landscape: The River Garonne, France. *Journal of the North American Benthological Society* 8(1):9-17.

Christy, J. Personal communication. The Nature Conservancy, Oregon Field Office, 821 SE 14th Ave., Portland, OR 97214.

Chorley, Richard J. 1969. *Water, earth and man: a synthesis of hydrology, geomorphology and socio-economic geogrpahy*. London: Methuen.

Cloud, John. 2001. Imaging the world in a barrel: CORONA and the clandestine convergence of the earth sciences. *Social Studies of Science* 31(2): 231-251.

Cohen, Warren B., and Maria Fiorella. 1998. Comparison of methods for detecting conifer forest change with Thematic Mapper imagery. In *Remote Sensing Change Detection: Environmental Monitoring Methods and Applications*, eds. Ross S. Lunetta and Christopher D. Elvidge, 89-102. Chelsea, Michigan: Ann Arbor Press.

Cohen, Warren B., Maria Fiorella, John Gray, Eileen Helmer, and Karen Anderson. 1998. An efficient and accurate method for mapping forest clearcuts in the Pacific Northwest using Landsat imagery. *Photogrammetric Engineering & Remote Sensing* 64:293-300.

Cohen, Warren B., Thomas K. Maiersperger, Thomas A. Spies, and Doug R. Oetter. 2001. Modeling forest cover attributes as continuous variables in a regional context with Thematic Mapper data. *International Journal of Remote Sensing* 22(12):2279-2310.

Cohen, Warren B., and Thomas A. Spies. 1992. Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery. *Remote Sensing of Environment* 41(1):1-17.

Cohen, Warren B., Thomas A. Spies, and Maria Fiorella. 1995. Estimating the age and structure of forests in a multi-ownership landscape of western Oregon, U.S.A. *International Journal of Remote Sensing* 16(4):721-746.

Collins, John B., and Curtis E. Woodcock. 1994. Change detection using the Gramm-Schmidt transformation applied to mapping forest mortality. *Remote Sensing of Environment* 50(3):267-279.

Collins, John B., and Curtis E. Woodcock. 1996. An assessment of several linear change detection techniques for mapping forest mortality using multitemporal Landsat TM data. *Remote Sensing of Environment* 56(1):66-77.

[CAETEP] Committee on the Applications of Ecological Theory to Environmental Problems, National Research Council. 1986. *Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies*. Washington, D. C.: National Academy Press.

Congalton, Russell G., Kevin Birch, Rick Jones, Jay Powell, and James Schriever. 2000. Evaluating remotely sensed techniques for mapping riparian vegetation. Paper presented at the Second International Conference on Geospatial Information in Agriculture and Forestry, Buena Vista, FL.

Coppin, Pol R., and Marvin E. Bauer. 1996. Digital change detection in forest ecosystems with remote sensing imagery. *Remote Sensing Reviews* 13(3-4):207-234.

Corning, Howard McKinley. 1973. *Willamette landings: ghost towns of the river.* Portland: Oregon Historical Society.

Crist, Eric P. 1984. Effects of cultural and environmental factors on corn and soybean spectral development patterns. *Remote Sensing of Environment* 14(1):3-13.

Crist, Eric P., and Richard C. Cicone. 1984. A physically-based transformation of Thematic Mapper data- the TM Tasseled Cap. *IEEE Transactions on Geoscience and Remote Sensing* GE-22:256-263.

Crist, Eric P., R. Laurin, and Richard C. Cicone. 1986. Vegetation and soils information contained in transformed Thematic Mapper data. Paper presented at the IGARSS' 86 Symposium, Noordwijk, The Netherlands, 8-11 September.

Crist, Eric P., R. Laurin, J. E. Colwell, and R. J. Kauth. 1984. *Investigations of Vegetation and Soils Information Contained in Landsat Thematic Mapper and Multispectral Scanner Data.* Ann Arbor, MI: Environmental Research Institute of Michigan.

Cronon, William. 1996. Uncommon Ground. New York: W. W. Norton & Co.

Dawdy, David R. 1989. Feasibility of mapping riparian forests under natural conditions in California. Paper presented at Protection, Management, and Restoration for the 1990's: Proceedings of the California Riparian Systems Conference, Berkeley, CA.

Décamps, Henri. 1993. River margins and evironmental change. *Ecological Applications* 3(3):441-45.

Décamps, Henri, Madeleine Fortune, Francois Gazelle, and Guy Pautou. 1988. Historical influence of man on the riparian dynamics of a fluvial landscape. *Landscape Ecology* 1(3):163-73.

Delong, Michael D., and Merlyn A. Brusven. 1991. Classification and spatial mapping of riparian habitat with applications toward management of streams impacted by nonpoint source pollution. *Environmental Management* 15(4):565-571.

Dixon, Mark D., and W. Carter Johnson. 1999. Riparian vegetation along the middle Snake River, Idaho: zonation, geographical trends, and historical changes. *Great Basin Naturalist* 59(1):18-34.

Doppelt, Robert. 1993. The vital role of the scientific community in new river conservation strategies. *Journal of the North American Benthological Society* 12(2):189-93.

Downward, S. R., A. M. Gurnell, and A. Brookes. 1994. A methodology for quantifying river channel planform change using GIS. Paper presented at Variability in Stream Erosion and Sediment Transport conference, Canberra, Australia

Dykaar, Bruce B., and P. J. Jr. Wigington. 2000. Floodplain formation and cottonwood colonization patterns on the Willamette River, Oregon, USA. *Environmental Management* 25(1):87-104.

Eckhardt, D. W., and J. P. Verdin. 1990. Automated update of an irrigated lands GIS using SPOT HRV imagery. *Photogrammetric Engineering & Remote Sensing* 56:1515-1522.

Ehrensing, D. Personal communication. Department of Crop and Soil Science, Oregon State University, Corvallis, OR 97331.

Ehrlich, Daniele, John E. Estes, Joseph Scepan, and Kenneth C. McGwire. 1994. Crop area monitoring with an advanced agricultural information system. *Geocarto International* 9(4):31-42.

Emmanuel, R. 1997. Urban vegetational change as an indicator of demographic trends in cities: the case of Detroit. *Environment and Planning B: Planning and Design* 24:415-426.

[EPA] Environmental Protection Agency, Western Ecology Division, National Health and Environmental Effects Research Laboratory. 1997. *Pacific Northwest Research Program, May 1997 Peer Review*. Corvallis, Oregon.

ERDAS, 1999. *ERDAS Imagine Expert Classifier.* Atlanta: ERDAS, Inc.

Erickson, Donna L. 1995. Rural land use and land cover change: implications for local planning in the River Raisin watershed. *Land Use Policy* 12(3):223-236.

Fabos, Julius Gy. 1995. Introduction and overview: the greenway movement, uses and potentials of greenways. *Landscape and Urban Planning* 33:1-13.

Fabos, Julius Gy., and Jack Ahern. 1996. *Greenways: the beginning of an international movement.* New York: Elsevier.

[FEMAT] Forest Ecosystem Management Assessment Team. *Forest Ecosystem Management: An Ecological, Economic, and Social Assessment.* 1993. Washington, DC: USDA Forest Service.

Flink, Charles A. 1993. The American greenway movement. *Canadian Water Resources Journal* 18(3):485-492.

Forman, Richard T. T., and Michel Godron. 1986. *Landscape Ecology.* New York: John Wiley & Sons.

Franklin, Jerry. F., and C. T. Dyrness. 1988. *Natural vegetation of Oregon and Washington.* Corvallis: Oregon State University Press.

Frenkel, Robert E., Stanley V. Gregory, and James R. Sedell. 1991. The Willamette River: An ecosystem in need of a new vision. Unpublished monograph.

Frenkel, Robert E., Eric F. Heinitz, and S. Nimal Wickramaratne. 1983. *Vegetation changes in the Willamette River Greenway in Benton and Linn counties: 1972-1981.* Corvallis: Water Resources Research Institute, Oregon State University.

Frenkel, Robert E., S. Nimal Wickramaratne, and Eric F. Heinitz. 1984. Vegetation and land cover change in the Willamette River Greenway in Benton and Linn Counties, Oregon: 1972-1981. *Association of Pacific Coast Geographers Yearbook* 46:63-77.

Frissell, Christopher A., William J. Liss, Charles E. Warren, and Michael D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management* 10(2):199-214.

Fuller, R. M., G. B. Groom, and A. R. Jones. 1994. The land cover map of Great Britain: an automated classification of Landsat Thematic Mapper data. *Photogrammetric Engineering & Remote Sensing* 60(5):553-562.

Fung, Tung, and Ellsworth LeDrew. 1988. The determination of optimal threshold levels for change detection using various accuracy indices. *Photogrammetric Engineering & Remote Sensing* 54(10):1449-1454.

Furuseth, Owen J., and Robert E. Altman. 1991. Who's on the greenway: socioeconomic, demographic, and locational characteristics of greenway users. *Environmental Management* 15(3):329-336.

Gardiner, John L. 1999. Willamette River floodplain restoration study: section 905(b) reconnaissance report. Portland, Oregon, Philip Williams & Associates.

Geoghegan, Jacqueline, Lowell Jr. Pritchard, Yelena Ogneva-Himmelberger, Rinku Roy Chowdhury, Steven Sanderson, and B. L. II Turner. 1998. "Socializing the pixel" and "pixelizing the social" in land-use and land-cover change. Pages 51-69 in Liverman, Diana, Emilio F. Moran, Ronald R. Rindfuss, and Paul C. Stern, editors. *People and pixels: linking remote sensing and social science.* Washington, DC: National Academy Press.

Giller, Paul S., and Björn Malmqvist. 1998. *The Biology of Streams and Rivers.* Oxford: Oxford University Press.

Gleeson, George W. 1972. *The Return of a River: The Willamette River, Oregon.* Corvallis, OR: Water Resources Research Institute, Oregon State University.

Good, James W. 1992. Ocean Shore Protection Policy and Practices in Oregon: An Evaluation of Implementation Success. Ph.D. dissertation, Department of Geosciences, Oregon State University.

Goodman, Majorie Smith. 1964. Criteria for the identification of types of farming on aerial photographs. *Photogrammetric Engineering* 30:984-990.

Gosselink, James G., Gary P. Shaffer, Lyndon C. Lee, David M. Burdick, Daniel L. Childers, Nancy C. Leibowitz, Susan C. Hamilton, Roel Boumans, Douglas Cushman, Sherri Fields, Marguerite Koch, and Jenneke M. Visser. 1990. Landscape conservation in a forested wetland watershed: Can we manage cumulative impacts? *BioScience* 40(8):588-600.

Goudie, Andrew. 1994. *The Human Impact on the Natural Environment.* 4th ed. Cambridge, Mass.: The MIT Press.

Goulter, I. C., and D. Forrest. 1987. Use of geographic information systems (GIS) in river basin management. *Water Science and Technology* 19(9):81-86.

Goward, S. N., and S. W. Wharton. 1984. Use of the TM Tasseled Cap transform for interpretation of spectral contrasts in an urban scene. Paper presented at Proceedings of the Symposium on Machine Processing of Remotely Sensed Data.

Graf, William L. 2001. Damage control: restoring the physical integrity of America's rivers. *Annals of the Association of American Geographers* 91(1):1-27.

Gregory, Stanley V. 1999. Ecological, demographic, and economic evaluation of opportunities and constraints for riparian restoration.

Gregory, S. V., D. W. Hulse, D. H. Landers, and E. Whitelaw. 1998. Integration of biophysical and socioeconomic patterns in riparian restoration of large rivers. In Wheater, Howard and Celia Kirby, editors. *Hydrology in a Changing Environment.* Chichester: John Wiley and Sons.

Gregory, Stanley, Dixon Landers, Linda Ashkenas, Randy Wildman, Paula Minear, Doug Oetter, Peter Bayley, Chip Andrus, Monty Pearson, and Sam Fernald. In preparation. Historical and future trajectories of floodplains, forests, and off-channel habitats of the mainstem Willamette River.

Gregory, Stanley V., Frederick J. Swanson, W. Arthur McKee, and Kenneth W. Cummins. 1991. An ecosystem perspective of riparian zones. *BioScience* 41(8):540-51.

Gross, Meir, Julius Gy. Fabos, Charles L. Tracy, and Michael Waltuch. 1987. Computer-assisted land use planning: a study of the Connecticut Greenway. *Land Use Policy* 4(1):31-41.

Grove, Noel. 1990. Greenways: paths to the future. *National Geographic* 177(6):77-99.

Guelke, Leonard. 1971. Problems of scientific explanation in geography. *Canadian Geographer* 15(1):38-53.

Gurnell, A. M. 1997. Channel change on the River Dee meanders, 1946-1992, from the analysis of air photographs. *Regulated Rivers: Research & Management* 13:13-26.

Gurnell, Angela M. 1997. The hydrological and geomorphological significance of forested floodplains. *Global Ecology and Biogeography Letters* 6(3/4):219-229.

Gustafson, Greg C., Thomas L. Daniels, and Rosalyn P. Shirack. 1982. The Oregon land use act. *Journal of the American Planning Association* 48(3):365-373.

Gutowsky, Sharon L. 2000. Riparian cover changes associated with flow regulation and bank stabilization along the Upper Willamette River in Oregon between 1939 and 1996. M.S. thesis, Department of Geosciences, Oregon State University.

Gutowsky, Sharon, and Julia A. Jones. 2000. Riparian cover changes along the upper Willamette River, 1939 to 1996. Paper presented at International Conference on Riparian Ecology and Management in Multi-land use Watersheds, Portland, OR.

Haack, Barry, Nevin Bryant, and Steven Adams. 1987. An assessment of Landsat MSS and TM data for urban and near-urban land-cover digital classification. *Remote Sensing of Environment* 21:201-213.

Haines-Young, Roy H., David R. Green, and Steven Cousins. 1993. *Landscape Ecology and Geographic Information Systems*. London: Taylor & Francis.

Harrald, John R., Kirk R. Karwan, Joseph V. Leotta, and William A. Wallace. 1979. Assessing the effectiveness of a marine environmental protection program. In *Program evaluation in the public sector*, eds. Albert C. Hyde and Jay M. Shafritz, 346-356. New York: Praeger.

Harris, Richard R., Peter Hopkinson, Sarah McCaffrey, and Lynn Huntsinger. 1997. Comparison of a Geographical Information System versus manual techniques for land cover analysis in a riparian restoration project. *Journal of Soil and Water Conservation* 52(2):112-117.

Hayes, Daniel J., and Steven A. Sader. 2001. Comparison of change-detection techniques for monitoring tropical forest clearing and vegetation regrowth in a time series. *Photogrammetric Engineering & Remote Sensing* 67(9):1067-1075.

Healy, Robert G. 1976. *Land use and the states*. Baltimore: Resources for the Future.

Helmer, Eileen H. 2000. The landscape ecology of tropical secondary forest in montane Costa Rica. *Ecosystems* 3:98-114.

Hendrix, William G., Julius Gy. Fabos, and Joan E. Price. 1988. An ecological approach to landscape planning using geographic information system technology. *Landscape and Urban Planning* 15(3/4):211-25.

Henebry, Geoffrey M. 1993. Detecting change in grasslands using measures of spatial dependence with Landsat TM data. *Remote Sensing of Environment* 46(2):223-234.

Hewitt, Mason J. III. 1990. Synoptic inventory of riparian ecosystems: The utility of Landsat Thematic Mapper data. *Forest Ecology and Management* 33/34:605-620.

Hoar, Alexander R., and Michael J. Erwin. 1985. Relationships between the expansion of agriculture and the reduction of natural riparian habitat in the Missouri River floodplain of northeast Montana, 1938-1982. Paper presented at Proceedings of the First North American Symposium on Riparian Ecosystems and Their Management, Tucson, AZ.

Homer, Collin G., R. Douglas Ramsey, Thomas C. Jr. Edwards, and Allan Falconer. 1997. Landscape cover-type modeling using a multi-scene Thematic Mapper mosaic. *Photogrammetric Engineering & Remote Sensing* 63(1):59-67.

Honey, William D. Jr. *The Willamette River Greenway: Cultural and Environmental Interplay.* 1975. Corvallis, Oregon, Water Resources Research Institute .

Hoover, Anne P., and Margaret A. Shannon. 1995. Building greenway policies within a participatory democracy framework. *Landscape and Urban Planning* 33:433-459.

Hulse, D., Flaxman, M., Richey, D., Goorjian, L., Diethelm, D., Freemark, K., White, D., Hummon, C., Eilers, J., Bernert, J., and Radosevich, S. 1999. Possible Futures for the Muddy Creek Watershed, Benton County, Oregon. http://ise.uoregon.edu/Muddy/Muddy_abstract.html.

Hulse, David W., and Stanley V. Gregory. 2001. Alternative futures as an integrative framework for riparian restoration of large rivers. Pages 194-212 in Dale, Virginia H., and Richard A. Haeuber, editors. *Applying Ecological Principles to Land Management.* New York: Springer-Verlag.

Hupp, Cliff R. 1992. Riparian vegetation recovery pattterns following stream channelization: A geomorphic perspective. *Ecology* 73(4):1209-26.

Hupp, C. R., and W. R. Osterkamp, 1985. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms, Ecology, 66(3):670-681.

Hupp, Cliff R., and W. R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14(4):277-295.

Iverson, Louis R. 1988. Land-use changes in Illinois, USA: the influence of landscape attributes on current and historic land use. *Landscape Ecology* 2(1):45-61.

Iverson, Louis R., and Paul G. Risser. 1987. Analyzing long-term changes in vegetation with geographic information system and remotely sensed data. *Advances in Space Research* 7(11):183-194.

Iverson, Louis R., Diane L. Szafoni, Sharon E. Baum, and Elizabeth A. Cook. 2001. A riparian wildlife habitat evaluation scheme developed using GIS. *Environmental Management* 28(5):639-654.

Jackson, Philip L., and A. Jon Kimerling. 1993. *Atlas of the Pacific Northwest.* Corvallis, Oregon: Oregon State University Press.

Janssen, L. L. F., and H. Middelkoop. 1992. Knowledge-based crop classification of a Landsat Thematic Mapper image. *International Journal of Remote Sensing* 13(15):2827-2837.

Jensen, J. Granville. 1964. *Spatial Organization of Land Uses: The Willamette Valley.* Corvallis: Oregon State University.

Jensen, John R., Ken Rutchey, Marguerite S. Koch , and Sunil Narumalani. 1995. Inland wetland change detection in the Everglades water conservation Area 2A using a time series of normalized remotely sensed data. *Photogrammetric Engineering & Remote Sensing* 61(2):199-209.

Johannessen, Carl L., William A. Davenport, Artimus Millet, and Steven McWilliams. 1970. The vegetation of the Willamette Valley. *Annals of the Association of American Geographers* 61:286-302.

Johnson, Lucinda B. 1990. Analyzing spatial and temporal phenomena using geographical information systems: A review of ecological applications. *Landscape Ecology* 4(1):31-43.

Johnson, W. Carter. 1997. Equilibrium response of riparian vegetation to flow regulation in the Platte River, Nebraska. *Regulated Rivers: Research & Management* 13(5):403-415.

Johnson, W. Carter, Mark D. Dixon, Robert Simons , Susan Jenson, and Kevin Larson. 1995. Mapping the response of riparian vegetation to possible flow reductions in the Snake River, Idaho. *Geomorphology* 13(1-4):159-173.

Johnston, R J. 1993. Meet the challenge: make the change. In *The Challenge for Geography: A Changing World: A Changing Discipline*, ed. R J. Johnston, 151-180. Oxford: Blackwell.

Kaden, Stefan O. 1993. GIS in water-related environmental planning and management: problems and solutions. Paper presented at HydroGIS 93: Application of Geographical Information Systems to Hydrology and Water Resources, Wallingford,UK, 19-22 April.

Kaiser, Edward J., David R. Godschalk, and F. Stuart Chapin Jr. 1995. *Urban Land Use Planning*. Urbana: University of Illinois Press.

Karr, James R., and Isaac J. Schlosser. 1978. Water resources and the land-water interface. *Science* 201(21 July):229-34.

Kauth, R. J., and G. S. Thomas. 1976. The Tasseled Cap- a graphic description of the spectra-temporal development of agricultural crops as seen by Landsat. Paper presented at Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, West Lafayette, IN.

Kennedy, Robert E., and Warren B. Cohen. In press. Automated designation of tie-points for image-to-image coregistration. *International Journal of Remote Sensing*.

Kienast, Felix. 1993. Analysis of historic landscape patterns with a geographical information system- a methodological outline. *Landscape Ecology* 8(2):103-18.

Kleiman, R. E., and D. L. Erickson. 1996. Landscape change in an agricultural watershed: the effect of parcelization on riparian forest cover. *Environment and Planning B: Planning and Design* 23(1):25-36.

Kline, Jeffrey D., and Ralph J. Alig. 1999. Does land use planning slow the conversion of forest and farm lands? *Growth and Change* 30:3-22.

Kline, Jeffrey D., Ralph J. Alig, and Rebecca L. Johnson. 2000. Forest owner incentives to protect riparian habitat. *Ecological Economics* 33:29-43.

Kline, Jeffrey D., Alissa Moses, and Ralph J. Alig. 2001. Integrating urbanization into landscape-level ecological assessments. *Ecosystems* 4:3-18.

Kovacs, John M., Jinfei Wang, and Manuel Blanco-Correa. 2001. Mapping disturbances in a mangrove forest using multi-date Landsat TM imagery. *Environmental Management* 27(5):763-776.

Kovar, K., and H. P. Nachtnebel, eds. 1993. *HydroGIS 1993: Application of Geographic Information Systems in Hydrology and Water Resource Planning.* Wallingford, UK, International Association of Hydrological Sciences.

Labaree, Jonathan. 1992. *How Greenways Work: A Handbook on Ecology.* Ipswich, Mass.: National Park Service and the Atlantic Center for the Environment.

LaFayette, Russell, and Leonard F. DeBano. 1990. Watershed condition and riparian health: Linkages. In *Watershed Planning and Analysis in Action,* eds. Robert E. Riggins, E. Bruce Jones, Ranvir Singh, and Paul A. Rechard. New York: American Society of Civil Engineers.

Lam, Alven H. S. 1989. Geographic information systems for river corridor and wetland management. Paper presented at Wetlands and River Corridor Management conference, Berne, New York, 5-9 July.

Large, A. R. G., and G. E. Petts. 1992. Rehabilitation of river margins. In *The Rivers Handbook: Hydrological and Ecological Principles, Vol. 2,* edited by Calow, Peter and Geoffrey E. Petts. Oxford: Blackwell Scientific Publications.

Large, A. R. G., and G. E. Petts. 1996. Historical channel-floodplain dynamics along the River Trent: implications for river rehabilitation. *Applied Geography* 16(3): 191-209.

Lattin, Peter D., P. J. Jr. Wigington, Barbara E. Peniston, Dale R. Lindeman, Doug R. Oetter, and Thomas J. Moser. In review. Riparian land cover-land use and stream ecological conditions: a comparison of data derived from aerial photography and Landsat Thematic Mapper imagery. *Journal of the Water Resources Association.*

Lauver, Chris L,. and Jerry L. Whistler. 1993. A hierarchical classification of Landsat TM imagery to identify natural grassland areas and rare species habitat. *Photogrammetric Engineering & Remote Sensing* 59(5):627-634.

Lee, Christopher T., and Stuart E. Marsh. 1995. The use of archival Landsat MSS and ancillary data in a GIS environment to map historical change in an urban riparian habitat. *Photogrammetric Engineering & Remote Sensing* 61(8):999-1008.

Lee, K. H., and Ross S. Lunetta. 1995. Wetlands detection methods. In *Wetland and Environmental Applications of GIS*, eds. John G. Lyon and Jack McCarthy, 249-284. Boca Raton, Florida: Lewis Publishers.

Lehmann, A. and J.-B. Lachavanne. 1997. Geographic information systems and remote sensing in aquatic botany. *Aquatic Botany* 58(3-4):195-207.

Leland, David, Steven Anderson, and Donald J. Jr. Sterling. 1997. The Willamette- a river in peril. *Journal of the American Water Works Association* 89(11):73-83.

Leopold, Aldo. 1966. *A Sand County Almanac.* New York: Ballantine Books.

Leopold, Luna B. 1997. *Water, Rivers and Creeks.* Sausalito, Calif.: University Science Books.

Levia, D. F. 1998. Farmland conversion and residential development in north central Massachusetts. *Land Degradation & Development* 9:123-130.

Likens, Gene E., and Herbert F. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. *BioScience* 24(8):447-56.

Lillesand, Thomas M., and Ralph W. Kiefer. 2000. *Remote Sensing and Image Interpretation.* New York: John Wiley & Sons.

Lindsey, Greg, Maltie Maraj, and SonCheong Kuan. 2001. Access, equity, and urban greenways: an exploratory investigation. *The Professional Geographer* 53(3):332-346.

Little, Charles E. 1974. *The new Oregon trail: an account of the development and passage of state land-use legislation in Oregon.* Washington, DC: The Conservation Foundation.

Little, Charles E. 1990. *Greenways for America.* Baltimore: The Johns Hopkins University Press.

Llewellyn, D. W., Gary P. Shaffer, N. J. Craig, L. Creasman, D. Pashley, M. Swan, and C. Brown. 1996. A decision-support system for prioritizing restoration sites on the Mississippi River alluvial plain. *Conservation Biology* 10(5):1446-1455.

Lo, Thomas H. C., Frank L. Scarpace, and Thomas M. Lillesand. 1986. Use of multitemporal spectral profiles in agricultural land-cover classification. *Photogrammetric Engineering & Remote Sensing* 52(4):535-544.

Lowrance, Richard, Ralph Leonard, and Joseph Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. *Journal of Soil and Water Conservation* 40(1):87-91.

Lowrance, Richard, Robert Todd, Joseph Jr. Fail, Ole Jr. Hendrickson, Ralph Leonard, and Loris Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. *BioScience* 34(6):374-77.

Ludwig, Donald, Ray Hilborn, and Carl Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. *Science* 260(2 April):17,36.

Lunetta, Ross S., and Mary E. Balogh. 1999. Application of multi-temporal Landsat 5 TM imagery for wetland identification. *Photogrammetric Engineering & Remote Sensing* 65(11):1303-1310.

Macleod, Robb D., and Russell G. Congalton. 1998. A quantitative comparison of change-detection algorithms for monitoring eelgrass from remotely sensed data. *Photogrammetric Engineering & Remote Sensing* 64(3):207-216.

Malanson, George P. 1993. *Riparian Landscapes.* New York: Cambridge University Press.

Marcus, Melvin G. 1979. Coming full circle: physical geography in the twentieth century. *Annals of the Association of American Geographers* 69(4):521-532.

Mark, Melvin M., Gary T. Henry, and George Julnes. 2000. *Evaluation: an integrated framework for understanding, guiding, and improving public and nonprofit policies and programs.* San Francisco: Jossey-Bass.

Marsh, George Perkins. 1864. *Man and nature: or, physical geography as modified by human action.* New York: Charles Scribner.

Mather, A. S. 1986. *Land use.* Essex: Longman Group U. K. Ltd.

Mather, John R. 1984. *Water Resources: Distribution, Use, and Management.* New York: John Wiley & Sons.

May, Peter J. 1993. Mandate design and implementation: enhancing implementation efforts and shaping regulatory styles. *Journal of Policy Analysis and Management* 12(4):634-663.

Mazmanian, Daniel A., and Paul A. Sabatier. 1981. *Effective Policy Implementation.* Lexington, Mass.: Lexington Books.

McHarg, Ian. 1971. *Design with Nature.* Garden City, NY: Doubleday & Co., Inc.

McPherson, John Lawrence. 1992. The Willamette River Greenway: A Program Analysis. M.A. thesis, School of Urban Planning, University of Oregon.

Metzger, Jean Paul, and Etienne Muller. 1996. Characterizing the complexity of landscape boundaries by remote sensing. *Landscape Ecology* 11(2):65-77.

Michener, William K., and Paula F. Houhoulis. 1997. Detection of vegetation changes associated with extensive flooding in a forested ecosystem. *Photogrammetric Engineering & Remote Sensing* 63(12):1363-1374.

Milton, E. J., D. J. Gilvear, and I. D. Hooper. 1995. Investigating change in fluvial systems using remotely sensed data. In *Changing River Channels*, eds. Gurnell, Angela and Geoffrey Petts. Chichester: John Wiley & Sons.

Miniszewski, Gary. 1979. *Background Information for the Benton County Comprehensive Plan: Willamette River Greenway.* Corvallis, Oregon: Benton County Planning Commission.

Miniszewski, Gary, and Marguerite Nabeta. Willamette river greenway program renewal white paper. 1993.

Minshall, G Wayne. 1988. Stream ecosystem theory: A global perspective. *Journal of the North American Benthological Society* 7(4):263-88.

Mitchell, Bruce. 1989. *Geography and resource analysis.* New York: John Wiley & Sons, Inc.

Moser, T. Personal communication. Dynamac Corp., 200 SW 35th St., Corvallis, OR, 97333.

Moser, Thomas J., Dale R. Lindeman, P. J. Jr. Wigington, Michael J. Schuft, and John Van Sickle. In press. Methods for multi-spatial scale characterization of riparian corridors. *Journal of the American Water Resources Association.*

Mossa, J., and M. McLean. 1997. Channel planform and land cover changes on a mined river floodplain, Amite River, Louisiana, U. S. A. *Applied Geography* 17(1):43-54.

Mouat, David A. and Judith Lancaster. 1996. Use of remote sensing and GIS to identify vegetation change in the Upper San Pedro River watershed, Arizona. *Geocarto International* 11(2):55-67.

Mouat, David A., Glenda G. Mahin, and Judith Lancaster. 1993. Remote sensing techniques in the analysis of change detection. *Geocarto International* 2:39-50.

Muchoney, Douglas M., and Barry N. Haack. 1994. Change detection for monitoring forest defoliation. *Photogrammetric Engineering & Remote Sensing* 60(10):1243-1251.

Muckleston, Keith W. 1986. The changing uses of the Willamette River. *Beitrage zur Hydrologie* 6(Kirchzarten):41-57.

Muckleston, Keith W. 1990. Integrated water management in the United States. In *Integrated Water Management: International Experiences and Perspectives*, Bruce Mitchell, ed. London: Belhaven Press.

Mullane, Neil. 1997. The Willamette River of Oregon: a river restored? In *River quality: dynamics and restoration*, eds. Antonius Laenen and David A. Dunnette, 65-75. Boca Raton: Lewis Publishers.

Mullens, Jo Beth. 1995. Implementation of Regional Plans in the Pacific Northwest: an Analysis of the Northwest Power Planning Council's Water Budget and Model Conservation Standards 1984-1993. Ph.D. dissertation, Department of Geosciences, Oregon State University.

Muller, Etienne. 1997. Mapping riparian vegetation along rivers: old concepts and new methods. *Aquatic Botany* 58(3-4):411-437.

Muller, Etienne, Henri Décamps, and Michael K. Dobson. 1993. Contribution of space remote sensing to river studies. *Freshwater Biology* 29(2):301-312.

Munch, Ernest R. 1984. River Forum: a sore thumb on the Willamette. *Landmark* 1(2):24-25.

Mundie, R. M. 1982. Evaluating the effectiveness of local government farmland protection programs. *GeoJournal* 6(6):513-517.

Munro, D. C., and H. Touron. 1997. The estimation of marshland degradation in southern Iraq using multitemporal Landsat TM images. *International Journal of Remote Sensing* 18(7):1597-1606.

Nabeta, Marguerite, and Jim Payne. 1991. Background information for Willamette River Greenway Program work session, November 8, 1991. Memo.

Nagel, Stuart S. 1990. *Policy Theory and Policy Evaluation*. New York: Greenwood Press.

Naiman, Robert J., Henri Décamps, John Pastor , and Carol A. Johnston. 1988. The potential importance of boundaries to fluvial ecosystems. *Journal of the North American Benthological Society* 7(4):289-306.

Naiman, Robert J., Henri Décamps, and Michael Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3(2):209-12.

Narumalani, Sunil, Yingchun Zhou, and John R. Jensen. 1997. Application of remote sensing and geographic information systems to the delineation and analysis of riparian buffer zones. *Aquatic Botany* 58(3-4):393-409.

Naveh, Zev, and Arthur S. Lieberman. 1984. *Landscape Ecology: Theory and Applications*. New York: Springer-Verlag.

Neale, Christopher M. U. 1997. Classification and mapping of riparian systems using airborne multispectral videography. *Restoration Ecology* 5(4S):103-112.

Nelson, Arthur C., and Terry Moore. 1996. Assessing growth management policy implementation: case study of the United States' leading growth management state. *Land Use Policy* 13(4):241-259.

Nelson, Gerald C., and Daniel Hellerstein. 1997. Do roads cause deforestation? using satellite images in econometric analysis of land use. *American Journal of Agricultural Economics* 79:80-88.

Newson, Malcolm D. 1992. River conservation and catchment management: a UK perspective. In *River Conservation and Management*, P. J. Boon, P. Calow, and G. E. Petts, eds. New York: John Wiley & Sons.

Newson, Malcolm D. 1997. *Land, Water, and Development: Sustainable Management of River Basin Systems, 2nd ed.* London: Routledge.

[NPS] National Park Service Rivers, Trails and Conservation Assistance Program. 1995. *Economic Impacts of Protecting Rivers, Trails, and Greenway Corridors: A Resource Book*. Washington, D. C.: National Park Service.

[NRC-CRAE] National Research Council Committee on Restoration of Aquatic Ecosystems- Science, Technology and Public Policy. 1992. *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy.* Washington, D. C.: National Academy Press.

Oetter, Doug R., Linda R. Ashkenas, Stanley V. Gregory, and Paula J. Minear. In review. GIS methodology for characterizing historical conditions of the Willamette River floodplain, Oregon. *Transactions in GIS.*

Oetter, Doug R., Warren B. Cohen, Mercedes Berterretche, Thomas K. Maiersperger, and Robert E. Kennedy. 2001. Land cover mapping in an agricultural setting using multi-seasonal Thematic Mapper data. *Remote Sensing of Environment* 76(2):139-155.

[ODOT] Oregon Department of Transportation. Preliminary Willamette River Greenway Plan. 1974. San Francisco, Royston, Hanamoto, Beck & Abey.

Odum, Eugene P. 1978. Ecological importance of the riparian zone. Paper presented at Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems conference, Washington, DC.

Omernik, J. M. 1987. Ecoregions of the coterminous United States. *Annals of the Association of American Geographers* 77:118-125.

[ODA] Oregon Department of Agriculture. 1999. 1997-1998 Oregon Agriculture and Fisheries Statistics, http://www.oda.state.or.us/oass/con98.htm.

[OLCDC] Oregon Land Conservation and Development Commission. 1990. *Oregon's statewide planning goals.* Salem: OLCDC.

[OSPRB] Oregon State Parks and Recreation Branch, Department of Transportation. 1976. *A Proposal for the Willamette River Greenway.* Salem: Oregon State Parks and Recreation Branch, Department of Transportation.

[OSPRD] Oregon State Parks and Recreation Department. 1992. *Protecting the Best of Oregon, 2010 Plan Phase I, 1993-1999.* Salem: Oregon State Parks and Recreation Department.

[PNW-ERC] Pacific Northwest Ecosystem Research Consortium. 2000. The Pacific Northwest Ecosystem Research Consortium. http://www.orst.edu/dept/pnw-erc/index.htm.

[PNW-ERC] Pacific Northwest Ecosystem Research Consortium. 2002. *Willamette River Basin: A Planning Atlas, vol. 2.* David Hulse, ed. Corvallis: Oregon State University Press.

Palmer, Tim. 1986. *Endangered Rivers and the Conservation Movement.* Berkeley: University of California Press.

Panigrahy, S., and S. A. Sharma. 1997. Mapping of crop rotation using multidate Indian Remote Sensing Satellite digital data. *ISPRS Journal of Photogrammetry and Remote Sensing* 52(2):85-91.

Patterson, T. William. 1988. *Land use planning: techniques of implementation.* Malabar, FL: Robert E. Krieger Publishing Co.

Pattison, William D. 1964. The four traditions of geography. *Journal of Geography* 63:211-216.

Pax-Lenney, Mary, and Curtis E. Woodcock. 1997. Monitoring agricultural lands in Egypt with multitemporal Landsat TM imagery: How many images are needed? *Remote Sensing of Environment* 59(3):522-529.

Pax-Lenney, M., C. E. Woodcock, J. B. Collins, and H. Hamdi. 1996. The status of agricultural lands in Egypt: The use of multitemporal NDVI features derived from Landsat TM. *Remote Sensing of Environment* 56:8-20.

Pease, James R. 1982. Commercial farmland preservation in Oregon. *GeoJournal* 6(6):547-553.

Peterjohn, William T., and David L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. *Ecology* 65(5):1466-75.

Petts, Geoffrey. 1989. Historical analysis of fluvial hydrosystems. In *Historical Change of Large Alluvial Rivers: Western Europe*, Geoffrey E. Petts, H. Mueller, and A. L. Roux, eds. New York: John Wiley & Sons.

Petts, Geoffrey E., and Peter Calow. 1996. *River Flows and Channel Forms.* Oxford: Blackwell Science.

Petts, Geoffrey E., A. R. G. Large, M. T. Greenwood, and M. A. Bickerton. 1992. Floodplain assessment for restoration and conservation: linking hydrogeomorphology and ecology. In *Lowland Floodplain Rivers: Geomorphological Perspectives*, P. A. Carling and Geoffrey E. Petts, eds., 217-234. Chichester: John Wiley & Sons.

Petts, G. E., H. Moller, and L. Roux. 1989. *Historical Change of Large Alluvial Rivers: Western Europe.* New York: John Wiley & Sons.

Platt, John R. 1964. Strong inference. *Science* 146(16 October):347-353.

Platt, Rutherford H. 1992. Geographers and water policy. Paper presented at AWRA National Forum on Water Management Policy, Washington, DC.

Platt, Rutherford H. 1996. *Land Use and Society: Geography, Law, and Public Policy.* Washington, DC: Island Press.

Plunk, Dorsey E. Jr., Ken Morgan, and Leo Newland. 1990. Mapping impervious cover using Landsat TM data. *Journal of Soil and Water Conservation* 45(5):589-591.

Pressman, Jeffrey L. and Aaron Wildavsky. 1974. *Implementation.* Berkeley: The University of California Press.

Quayle, Moura. 1995. Urban greenways and public ways: realizing public ideas in a fragmented world. *Landscape and Urban Planning* 33:461-475.

Raad, Maureen F. 1999. Flood Damage Reduction and Riparian Floodplain Forest Restoration: Selecting Focal Areas and Setting Restoration Goals on Oregon's Willamette River. Masters Project, Department of Landscape Architecture, University of Oregon.

Rapp, Valerie. 1997. *What the River Reveals.* Seattle: The Mountaineers.

Rindfuss, Ronald R., and Paul C. Stern. 1998. Linking remote sensing and social science: the need and the challenges. In *People and pixels: linking remote sensing and social science*, Diana Liverman, Emilio F. Moran, Ronald R. Rindfuss, and Paul C. Stern, eds., 1-27. Washington, DC: National Academy Press.

River Network. 1995. Draft proposal for a Willamette River floodway project. Unpublished paper.

Robbins, William G. 1974. *Land: its use and abuse in Oregon, 1848-1910.* Corvallis: Oregon State University.

Robbins, William G. 1997. *Landscapes of Promise: The Oregon Story 1800-1940.* Seattle: University of Washington Press.

Rohse, Mitch. 1987. *Land-Use Planning in Oregon: A No-Nonsense Handbook in Plain English.* Corvallis: Oregon State University Press.

Rossi, Peter H., Howard E. Freeman, and Sonia R. Wright. 1979. *Evaluation: a systematic approach.* Beverly Hills: Sage Publications.

Roth, Nancy E., J. David Allan, and Donna L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology* 11(3):141-156.

Rowlinson, Lisa C., Mark Summerton, and Fethi Ahmed. 1999. Comparison of remote sensing data sources and techniques for identifying and classifying alien invasive vegetation in riparian zones. *Water SA* 25(4):497-500.

Russell, Emily W. B. 1997. *People and Land through Time.* New Haven: Yale University Press.

Russell, Gordon D., Charles P. Hawkins, and Michael P. O'Neill. 1997. The role of GIS in selecting sites for riparian restoration based on hydrology and land use. *Restoration Ecology* 5(4S):56-68.

Ryder, Barbara A. 1995. Greenway planning and growth management: partners in conservation? *Landscape and Urban Planning* 33:417-432.

Ryerson, Robert A., Richard N. Dobbins, and Christian Thibault. 1985. Timely crop area estimates from Landsat. *Photogrammetric Engineering & Remote Sensing* 51(11):1735-1743.

San Miguel-Ayanz, Jesús, and Gregory S. Biging. 1997. Comparison of single-stage and multi-stage classification approaches for cover type mapping with TM and SPOT data. *Remote Sensing of Environment* 59(1):92-104.

Sauer, Carl Ortwin. 1956. The education of a geographer. *Annals of the Association of American Geographers* 46:287-299.

Schiemer, Fritz, Christian Baumgartner, and Klement Tockner. 1999. Restoration of floodplain rivers: the 'Danube Restoration Project'. *Regulated Rivers: Research & Management* 15(1-3):231-244.

Schlosser, Isaac J., and James R. Karr. 1981. Water quality in agricultural watersheds: Impact of riparian vegetation during base flow. *Water Resources Research* 17(2):233-40.

Schriever, James R., and Russell G. Congalton. 1995. Evaluating seasonal variability as an aid to cover-type mapping from Landsat Thematic Mapper data in the Northeast. *Photogrammetric Engineering & Remote Sensing* 61(3):321-327.

Schulte, Lisa A., and David J. Mladenoff. 2001. The original U. S. public land survey records: their use and limitations in reconstructing presettlement vegetation. *Journal of Forestry* 99(10):5-10.

Schwarz, Loring LaB. 1993. *Greenways: A Guide to Planning, Design, and Development.* Charles A. Flink and Robert M. Searns, eds. Covelo, CA.: Island Press.

Sedell, James R., and Judith L. Froggatt. 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U S A, from its floodplain by snagging and streamside forest removal. *Verh. Internat. Verein. Limnol.* 22:1828-34.

Sedell, James R., Robert J. Steedman, Henry A. Regier, and Stanley V. Gregory. 1991. Restoration of human impacted land-water ecotones. In *Ecotones: The Role of Landscape Boundaries in the Management and Restoration of Changing Environments*, eds. Marjorie M. Holland, Paul G. Risser, and Robert J. Naiman, 110-129. New York: Routledge, Chapman, and Hall.

Shaffer, Mark L., J. Michael Scott, and Frank Casey. 2002. Noah's options: initial cost estimates of a national system of habitat conservation areas in the United States. *BioScience* 52(5):439-443.

Shankman, David. 1993. Channel migration and vegetation patterns in the Southeastern coastal plain. *Conservation Biology* 7:176-183.

Shrubsole, Dan. 1992. The Grand River Conservation Commission: history, activities, and implications for water management. *The Canadian Geographer* 36(3):221-236.

Shueb, Saleh, and Pete Atkins. 1991. Crop area estimation: a comparison of remote sensing and census methods. *Geography* 76(3):235-239.

Slocombe, D Scott. 1993. Implementing ecosystem-based management. *BioScience* 43(9):612-622.

Smith, Daniel S. 1993. An overview of greenways: their history, ecological context, and specific functions. In *Ecology of Greenways: Design and Function of Linear Conservation Areas*, eds. Daniel S. Smith and Paul Cawood Hellmund, 1-22. Minneapolis: University of Minnesota Press.

Smith, Daniel S., and Paul Cawood Hellmund. 1993. *Ecology of Greenways: Design and Function of Linear Conservation Areas*. Minneapolis: University of Minnesota Press.

Smith, John W., Zulhizzan Ishak-Muhamad, and Ewe Leng Lim. 1990. Utility of a GIS in watershed management- A case study. In *Watershed Planning and Analysis in Action*, eds. Robert E. Riggins, E. Bruce Jones, Ranvir Singh, and Paul A. Rechard. New York: American Society of Civil Engineers.

Spies, Thomas A., William J. Ripple, and Gay A. Bradshaw. 1994. Dynamics and pattern of a managed coniferous landscape in Oregon. *Ecological Applications* 4:555-568.

Squires, Donald F. 1992. Quantifying anthropogenic shoreline modification of the Hudson River and estuary from European contact to modern time. *Coastal Management* 20:343-54.

Starbird, Ethel A. 1972. A river restored: Oregon's Willamette. *National Geographic* 141(6):816-835.

Stoddart, David Ross. 1986. *On geography and its history*. New York: B. Blackwell.

Stow, D A. 1993. The role of geographic information systems for landscape ecological studies. In *Landscape Ecology and Geographic Information Systems*, eds. Roy H. Haines-Young, David R. Green, and Steven Cousins, 11-21. London: Taylor & Francis.

Swanson, Frederick J., Stanley V. Gregory, James R. Sedell, and A. G. Campbell. 1982. Land-water interactions: the riparian zone. In *Analysis of Coniferous Forest Ecosystems in the Western U. S.*, ed. Robert L. Edmonds, 267-291. Stroudsburg, PA: Hutchinson Ross Publishing Co.

Tabacchi, Eric, Anne-Marie Planty-Tabacchi, and Odile Décamps. 1990. Continuity and discontinuity of the riparian vegetation along a fluvial corridor. *Landscape Ecology* 5(1):9-20.

Theobald, David M., and N. Thompson Hobbs. 1998. Forecasting rural land-use change: a comparison of regression- and spatial transition-based models. *Geographical & Environmental Modelling* 2(1):65-82.

Thomas, William L Jr. *Man's Role in Changing the Face of the Earth*. 1956. Chicago: University of Chicago Press.

Thorne, James F. 1993. Landscape ecology. In *Ecology of Greenways: Design and Function of Linear Conservation Areas*, eds. Daniel S. Smith and Paul Cawood Hellmund, 23-42. Minneapolis: University of Minnesota Press.

Towle, Jerry C. 1982. Changing geography of Willamette Valley woodlands. *Oregon Historical Quarterly* 83(1):67-90.

Tuchmann, E. T., Connaughton, K. P., Freedman, L. E., and Moriwaki, C. B. 1996. *The Northwest Forest Plan: A Report to the President and Congress.* Portland, OR: USDA Office of Forestry and Economic Assistance.

Turner, B. L. II, and W. B. Meyer. 1994. Global land-use and land-cover change: an overview. In *Changes in Land Use and Land Cover: A Global Perspective*, eds. W. B Meyer and B. L. II Turner. Cambridge: Cambridge University Press.

Turner, B. L. II, William B. Meyer, and David L. Skole. 1994. Global land-use/land-cover change: towards an integrated study. *Ambio* 23(1):91-95.

Turner, Monica G., David N. Wear, and Richard O. Flamm. 1996. Land ownership and land-cover change in the southern Appalachian highlands and the Olympic peninsula. *Ecological Applications* 6(4):1150-1172.

Turner, Monica Goigel. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* 20:171-197.

Turner, Monica Goigel, and C. Lynn Ruscher. 1988. Changes in landscape patterns in Georgia, USA. *Landscape Ecology* 1(4):241-51.

Uhrich, M. A., and D. A. Wentz. 1999. *Environmental Setting of the Willamette Basin, Oregon.* Portland, OR: USGS National Water Quality Assessment Program.

[ACOE] U. S. Army Corps of Engineers. 1895. *Willamette River, Oregon, Portland to Eugene.* Map series.

[ACOE] U. S. Army Corps of Engineers. 1932. *Willamette River, Oregon, Portland to Eugene.* Map series.

Valladares, Miguel Angel. 1993. Effects of EC policy implementation on natural Spanish habitats. *The Science of the Total Environment* 129:71-82.

Vannote, Robin L., G. Wayne Minshall, Kenneth W. Cummins, James R. Sedell, and Colbert E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Science* 37:130-37.

Vogelmann, J. E., T. Sohl, and S. M. Howard. 1998. Regional characterization of land cover using multiple sources of data. *Photogrammetric Engineering & Remote Sensing* 64(1):45-57.

Ward, J. V., and J. A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation . *Regulated Rivers* 11(1):105-119.

Ward, J. V., Klement Tockner, and Fritz Schiemer . 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. *Regulated Rivers: Research & Management* 15(1-3:125-139.

Wear, David N., and Paul Bolstad. 1998. Land-use changes in Southern Appalachian landscapes: spatial analysis and forecast evaluation. *Ecosystems* 1:575-594.

Wear, David N., Rei Liu, J. Michael Foreman, and Raymond M. Sheffield. 1999. The effects of population growth on timber management and inventories in Virginia. *Forest Ecology and Management* 118:107-115.

Weber, Robert M., and Glenn A. Dunno. 2001. Riparian vegetation mapping and image processing techniques, Hopi Indian Reservation, Arizona. *Photogrammetric Engineering & Remote Sensing* 67(2):179-186.

White, Gilbert F. 1972. Environmental impact statements. *The Professional Geographer* 24(4):302-309.

White, Gilbert F. 1977. *Environmental Effects of Complex River Development.* Boulder: Westview Press.

White, Richard. 1995. *The Organic Machine.* New York: Hill and Wang.

Wickham, James D., Robert V. O'Neill, Kurt H. Riitters, Timothy G. Wade, and K. Bruce Jones. 1997. Sensitivity of selected landscape pattern metrics to land-cover misclassification and differences in land-cover composition. *Photogrammetric Engineering & Remote Sensing* 63(4):397-402.

Wickramaratne, Siri Nimal. 1983. Vegetation changes in the Willamette River Greenway, Benton and Linn counties, Oregon, 1972-1981. M.S. thesis, Department of Geography, Oregon State University.

Wickware, Gregory M., and Howarth Philip J. 1981. Change detection in the Peace-Athabasca delta using digital Landsat data. *Remote Sensing of Environment* 11(1):9-25.

Willamette Restoration Initiative. 2001. *Restoring a river of life: the Willamette restoration strategy overview.* Salem, OR: Willamette Restoration Initiative.

Willamette Riverkeeper. 1996. *Riverlands Report.* Portland, OR: Willamette Riverkeeper.

Willamette Valley Livability Forum. 1999. About the Willamette Livability Forum, http://www.econ.state.or.us/wvlf/.

Williams, Donald C., and John G. Lyon. 1997. Historical aerial photographs and a geographic information system (GIS) to determine effects of long-term water level fluctuations on wetlands along the St. Mary's River, Michigan, USA. *Aquatic Botany* 58:363-378.

Williams, Vicki L., Warren R. Philipson, and William D. Philpot. 1987. Identifying vegetable crops with Landsat Thematic Mapper data. *Photogrammetric Engineering & Remote Sensing* 53(2):187-191.

Wilson, Mark Shelton. 1994. Origins of the Old-growth Forest Conflict (1971-1989): A New Model for Resource Allocation. Ph.D. dissertation, Department of Geosciences, Oregon State University.

Winterbottom, Sandra J., and David J. Gilvear. 2000. A GIS-based approach to mapping probablilities of river bank erosion: regulated River Tummel, Scotland. *Regulated Rivers: Research & Management* 16(2):127-140.

Wolter, Peter T., David J. Mladenoff, George E. Host, and Thomas R. Crow. 1995. Improved forest classification in the Northern Lake States using multi-temporal Landsat imagery. *Photogrammetric Engineering & Remote Sensing* 61(9):1129-1143.

Wright, Andrea, W. Andrew Marcus, and Richard Aspinall. 2000. Evaluation of multispectral, fine scale digital imagery as a tool for mapping stream morphology. *Geomorphology* 33:107-120.

Zhuang, Xin, Bernard A. Engel, Marion F. Baumgardner, and Philip H. Swain. 1991. Improving classification of crop residues using digital land ownership data and Landsat TM imagery. *Photogrammetric Engineering & Remote Sensing* 57(11):1487-1492.