ASSESSING LAND USE AND RIPARIAN Buffers Along Maine's Presumpscot Watershed Using Landsat Thematic Mapper

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ABSTRACT

This study assesses land use within Maine's Presumpscot river watershed using a land-change science framework. This framework calls for monitoring dynamic landscapes shaped by coupled human and natural processes so as to understand their causes and consequences. Industrial uses of the river since early European settlement activity significantly altered its hydrology and ecosystem characteristics. Moreover, recent population growth in this, the fastest growing, region of Maine has put significant development pressures on land adjoining the river. Landsat Thematic Mapper data are used to analyze the configuration of land use classes for the watershed and a buffer analysis is conducted to document dominant land use activities within zones of the river. The results indicate a fragmentation of green space along the river due to agriculture and development activities, and the buffer analysis points to an inverse relationship between the proportion of green space and distance from river. While the findings are not unexpected, they raise important concerns for the future health of the Presumpscot ecosystem from pollution and the expansion of development.
Keywords: Land use, riparian buffers, remote sensing, Presumpscot River, Maine

Introduction

The lower Presumpscot River flows from Lake Sebago, through Cumberland County, and into Casco Bay, Maine. Its floodplain and estuary provide evidence of early settlement activity by Native American farming and fishing communities and European trading outposts (Blake 1975; Bourque 2001). The name Presumpscot translates from the Abenaki language as "ledges in channel," or often alternatively interpreted as "many falls," which is in keeping with early descriptions of the river (Bright 2004). It is also the site of many firsts in riverine development for the state. It hosts the first dam, mill and hydroelectric dam ever built in the state and it saw a legislative victory as early as 1735 that ensured the passage of fish despite dam activity (Casco Bay Estuary Project (CBEP) 2003). Flowing through Maine's most populated and economically diverse county comprising nearly a quarter of the state's total population, the communities of Windham, Gorham, Westbrook, Falmouth, and Portland adjoin the banks of the Presumpscot and have all depended on its waters and resources since their establishment (Figure 1). Industries crucial to Maine's historic development and growth including the paper and pulp industry, fisheries, and hydropower have also benefited from the Presumpscot's resources. The river is the largest source of fresh water flowing into Casco Bay and as such provides a rich environment for the dependent estuarine ecosystem (CBEP 1996). The recent expansion of population and development in southern Maine, however, raise important concerns for land use change across the region and especially for the health of the Presumpscot and its adjoining floodplain.

In recent years numerous studies have highlighted threats to the sustainability of freshwater resources from increased demand, intensive agriculture, the expansion of development, and changes in global climate regimes (Mimikou et al. 2000; Vörösmarty et al. 2000; Alcamo, Flörke and Märker 2007). A recent report cited the Presumpscot including Lake Sebago as among the most vulnerable watersheds of the northeastern United States to development pressures. The Presumpscot basin is included in this list due to rapid recent urban expansion and the large numbers of people across southern Maine dependent on its surface waters for domestic and industrial freshwater needs (Barnes et al. 2009). Moreover, future development pressures are expected to intensify the threats to water quality across the basin. Given the vital role freshwater plays in meeting ecosystem and human needs, scientists have urgently called for the careful monitoring, management and protection of such source water supply regions to ensure their sustainability (Kundzewicz et al. 2007; Barnes et al. 2009).

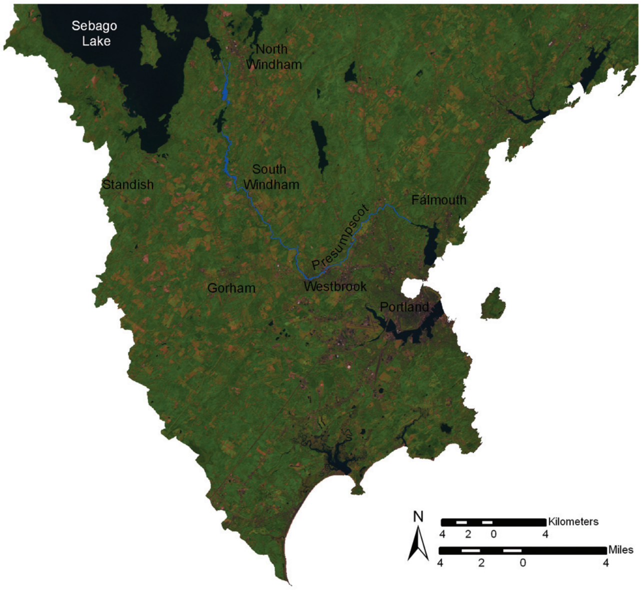


Figure 1. Presumpscot river watershed, Landsat Thematic Mapper composite Bands 3, 4, 5

Following this call and employing methods offered by the land-change science and remote sensing communities, our study uses Landsat imagery to monitor and document dominant land use activities across the Presumpscot river watershed and focus particularly on the most vulnerable immediate one mile buffer along the river (DeFries, Asner, and Houghton 2004; Turner, Lambin, and Reenberg 2007). Riparian buffers, with their restrictions on development, have long since provided a means to manage and protect rivers from the stressors of agriculture, urban development or other land use conversions. Within the state of Maine, the Mandatory Shoreland Zoning Act (MSZA) of 1971 requires a 250 ft buffer around all ponds over 10 acres, salt marshes, tidal zones and rivers with drainage basins over 64.75 sq. km. (25 sq. miles). Development activity is closely regulated within the buffer zone to protect and conserve unique ecosystems and control and prevent water pollution (Maine Department of Environmental Protection (ME DEP) 2008b). Buffers provide ecosystem services including habitat, food and migration corridors for wildlife, and they have the ability to link patches of forests or wetlands that may have been fragmented due to the expansion of agriculture or urban development (Cox 1996). These corridor connectors also augment the probability of plant and animal species survival (Harker et al. 1993). Studies indicate that the effectiveness of riparian buffers in pollution abatement has to do both with the width of the buffer itself, and soil type, hydrology and biochemistry considerations. Collectively, these conditions aid in mitigating nutrient overload, stabilizing river banks, and minimizing erosion and flood damage (Mayer et al. 2005). As Gregory et al. (1991) point out, their ecosystem contributions, then, far exceed their relative sizes when compared to other landscape features.

Collecting land use information before the advent of remote sensing systems was an arduous process that required significant field time. Nevertheless, land use information was and is vital to the work of geographers interested in understanding and explaining patterns of interaction between humans and their environment. Over the past forty plus years, satellite remote sensing technology has seen advances that now allow us to document and monitor earth surface processes at a variety of spatial, spectral and temporal scales (Lillesand, Kiefer, and Chipman 2008). In so doing, this technology offers many advantages for land use studies. It has considerably simplified the task of collecting information about the landscape. The digital format in which this information is collected easily lends itself to computationally intensive analysis. The snapshot view or systematic repeat coverage of satellite remote sensing allows us to monitor dynamic landscape patterns at weekly, monthly, seasonal, annual or decadal intervals. Data beyond the visible from the near and mid infrared portion of the electromagnetic spectrum provide important information on vegetation health and vigor, soil conditions, water features and urban areas and, as such, are vital to understanding land use processes and spatial patterns (Campbell 2007). Data from the National Aeronautics and Space Administration's (NASA) Landsat series of sensors are now freely downloadable and provide all these advantages, transforming the way land use and land cover science is done (Yang and Lo 2002; Xian, Crane and Su 2007; Bahnzahf, Grescho and Kindler 2009; Petrov and Sugumaran 2009). Our use of a remote sensing based approach for this study provides these advantages and a synoptic view of the Presumpscot landscape. Going forward, this study can provide a baseline for comparison and highlight areas within the watershed particularly vulnerable to change and requiring special land management considerations.

The River and a History of Use

Agriculture was the predominant form of land use around the Presumpscot floodplain by Native American Abenaki groups who found fertile locations upstream from the Presumpscot's estuary (CBEP 2003). Documents suggest that early European settlement activity across the larger region started in the 1650s with the clearing of forests and the use of the river as a transport route into the interior (Blake 1975; Bourque 2001). Industrial uses of the river dominated from the 1700s through the present day, with evidence of saw, grist, and paper and pulp mills appearing during the 1700s (Eves 1992). By 1867, seven of the current nine dams on the Presumpscot were recorded by name and actively used to power paper, wool, textile mills and iron works (Goodale 1868). In 1880, the S.D. Warren mill at Westbrook would be considered the "largest paper mill in the world" (Warren 1973).

The continued industrial use of the river well into the twentieth century, however, left the river polluted, channelized, and its water flow restricted in its lower reaches (ME DEP 1999). Clearly, it was far from the swift flowing river with many falls as its name suggested (Blake 1975). Reports in the 1970s even went as far to suggest that fumes from the Presumpscot were thought to have caused "paint to peel from nearby homes" (Sun Journal 2008), while the river from Westbrook to its mouth in Casco Bay was described as an "industrial sewer" (Blake 1975, 5). The Presumpscot river estuary and Casco Bay were compared to the country's most polluted harbors toward the end of the twentieth century and the river was listed on the Maine Department of Environmental Protection's (ME DEP) List of Impaired Waterbodies due to high levels of total suspended solids and low dissolved oxygen (Northern Ecological Associates, Inc. (NEA) 2005; ME DEP 2008a).

The river currently has nine dams, eight of which are owned by the South African Pulp and Paper Incorporated (SAPPI). SAPPI acquired the 1854-founded S.D.Warren Co. in 1995 to launch its North American presence. In 1995, SAPPI filed for a renewal of its five hydroelectric dams on the Presumpscot under Federal Energy Regulatory Commission (FERC) guidelines, but protested when it was required to file water quality certifications with the ME DEP as well (Environmental News Service (ENS) 2006). This disagreement eventually resulted in an important 2006 U.S. Supreme Court case decision which upheld states' rights in the S.D Warren Co. v. Maine Board of Environmental Protection ruling. The ruling stated that "operators of hydroelectric dams must meet a state's water quality requirements in order to qualify for a federal license" (Greenhouse 2006). In 2003, SAPPI was granted renewal for each of its dams by FERC, but was required to install fish passages at dam sites and allow minimum water flows to mitigate low dissolved oxygen levels (ENS 2006). The case proved to be a significant victory for environmental groups not just associated with the Presumpscot, but with rivers nationwide.

Efforts to reverse the river's health began as early as the 1960s in response to legislation and public outcry. In the early 1960s, the S.D. Warren Co. (now the South African Pulp and Paper Incorporated - SAPPI) constructed settling lagoons and treatment plants to partially mitigate wastes from its Westbrook paper mill (Blake 1975). Municipal sewage treatment plants for all communities adjoining the river were established by the 1970s and significantly aided the repair of the river ecosystem (Blake 1975; Greater Portland Council of Governments (GPCG) 1993).

In 1992 the Maine Department of Inland Fisheries and Wildlife established a salmon and trout fishery just below Sebago Lake. With combined efforts spurred on by the Clean Water Act and the eventual closing of many mills, the health of the river steadily improved (ME DEP 2008a). The SAPPI paper mill in Westbrook, a primary pollution source for the lower river, ceased its pulping activities in 1999 the Smelt Hill dam near the Presumpscot estuary was removed in 2002 reopening seven miles of potential habitat to the *Alosa sapidissima* (American shad), *Salmo salar* (Atlantic salmon), and *Alosa pseudoharengus* (alewives) among other species (CBEP 2003; ME DEP 2008a). The main stem of the Presumpscot below the Sacarappa Dam in Westbrook was subsequently delisted from the impaired listings for the state and considered a major success for the health of the river (ME DEP 2008a).

Despite these positive developments, urban and agricultural non-point sources of pollution, including high levels of phosphorous, continue to degrade the river, while a section of the river at Westbrook remains on the list for impaired waterbodies for the presence of high *Escherichia coli* levels (ME DEP 2008a). Particularly vulnerable are smaller tributaries feeding into the main stem of the Presumpscot River. These are susceptible to non-point source pollution as Maine's MSZA does not require protective buffers along smaller streams. Meanwhile, local efforts by government agencies and strong local grassroots organizations continue to work toward a sustainable and thriving Presumpscot by monitoring water quality, expanding land for preservation and engaging in community education projects. The chief concerns today are non-point pollution sources, the fragmentation of the riparian buffer, and the rapid expansion of impervious surfaces due to development activities along the lower Presumpscot.

Data and Methods

This study uses a satellite image obtained from NASA's Landsat 5 Thematic Mapper (TM) multispectral sensor (WRS: Path 12/Row 30) to produce a land use map for the Presumpscot watershed, particularly concentrating on the 1 mile wide buffer along its banks. The six band dataset at 30 m spatial resolution from 7 September 2007 is downloaded from the Earth Resources Observation and Science (EROS) Data Center (United States Geologic Survey (USGS) EROS 2006). All image processing and analysis is conducted using ERDAS Imagine 9.3 software, while spatial statistics and final maps are completed in ESRI's ArcGIS 9.2 software. The larger Landsat TM image is cropped to the extent of the Presumpscot watershed using a masking function within ERDAS Imagine. The extent of the watershed is derived from the Maine watershed data layer supplied by the Maine Office of Geographic Information Systems (Maine Geographic Information Systems (MEGIS) 2008).

The study uses conventional image processing techniques to examine land use for the Presumpscot watershed. For this study, an unsupervised classification using the Iterative Self Organizing Data Analysis (ISODATA) algorithm produces a land use map from the 2007 multispectral Landsat TM dataset. Unsupervised classifications identify and group together clusters of spectrally similar pixels within an image. These classifications are quick to conduct, minimize human error as only the number of classes is required as input by the user, and result in classes that are generally fairly homogenous (Campbell 2007). ISODATA clusters pixels into a predetermined number of classes based on a minimum distance function (Lillesand, Kiefer, and Chipman 2008). Once the number of classes has been assigned, the process randomly selects representative pixels as class centers. It then allows the algorithm using the minimum distance function to allocate pixels into classes (Campbell 2007). The iterative process allows adjustments in class and pixel membership until pixels retain membership within a particular class from one iteration to the next or a predefined number of iterations is reached (Lillesand, Kiefer, and Chipman 2008). After some experimentation, the ISODATA routine is run to assign image pixels into eight land use classes.

Classes are then examined closely and named based on detailed knowledge of the study region. To gauge the accuracy of the classification routine, accuracy assessments are performed using a stratified random sample of 80 points. The statistics generated through this process report overall accuracies and a Kappa index of agreement for the sample of points used. This index provides an assessment of the extent to which pixel assignment is due to 'true' versus 'chance' agreement (Lillesand, Kiefer, and Chipman 2008). High spatial resolution Google Earth imagery, field knowledge, and digital orthoimagery of the area available through MEGIS are used for verification. The final Presumpscot watershed land use map is exported into ArcGIS. ArcGIS' buffer tool is used to create 76 m (250 feet), 305 m (1000 feet) and 1.6 km (1 mile) buffers along the river. Finally, ArcGIS' Spatial Analyst toolbox and zonal statistics function provides the extent of total area under each of the land use categories within demarcated buffer zones along the river.

Analysis and Results

A visual assessment of the 2007 TM false color visible, near and mid infrared composite combining Bands 3, 4, 5 (Figure 1) indicate a landscape interspersed with urban and rural land uses. Urban land uses are observed closer toward the coast along the lower reaches of the Presumpscot and particularly around the cities of Westbrook, Falmouth and Portland as indicated. Sections of the central business district of the city of Westbrook directly abut the banks of the river. The larger region including Portland, Maine's largest city, is typified by medium and high density residential housing, industrial activities, and large commercial outlets. Road networks linking towns observe linear patterns of residential and industrial development and especially between Westbrook and Portland suburbs and along Interstate-95 that runs from south to north, west of the city of Portland. Residential expansion has taken place along major roads connecting towns like Gorham, South Windham, and Falmouth, which all serve as bedroom communities to the city of Portland.

Outside the city of Portland, rural land uses including open agricultural fields, pasture, tree cover and smaller villages dominate the landscape. Mid infrared Band 5 on the Thematic Mapper sensor does particularly well at identifying open agricultural fields as it picks up variations in moisture content from fallow fields and those with late-season crops. These areas also display characteristic geometric field patterns southeast of Standish and south of the town of North Windham. Upstream and northeast from the town of South Windham, the Presumpscot winds through agricultural fields interspersed with tree covered private land. Development activities are observed along highways and utility lines cutting through forested sections are also clearly observed on the image composite.

Thematic Mapper visible, near and mid infrared Bands 3, 4, 5, and 7 from September 2007 are used in an unsupervised ISODATA classification. This iterative minimum distance function yielded eight classes representing broad land use patterns for the watershed. After a visual analysis incorporating information from field visits, the False Color Composite (FCC) and high spatial resolution digital orthimagery, the classes are named as observed in Figure 2. Table 1 provides descriptions and reports summary statistics for each land use category. Urban, mud flats and mixed developed classes collectively comprise approximately 30 percent of the watershed while tree cover classes comprise 36 percent and agricultural fields, undeveloped land and pastures report 24 percent. Due to the coarse 30 m spatial resolution of the TM image there is bound to be some mixing of land use classes. Using generalized land use categories as done here leaves some room for interpretation and minimizes interpretation errors.

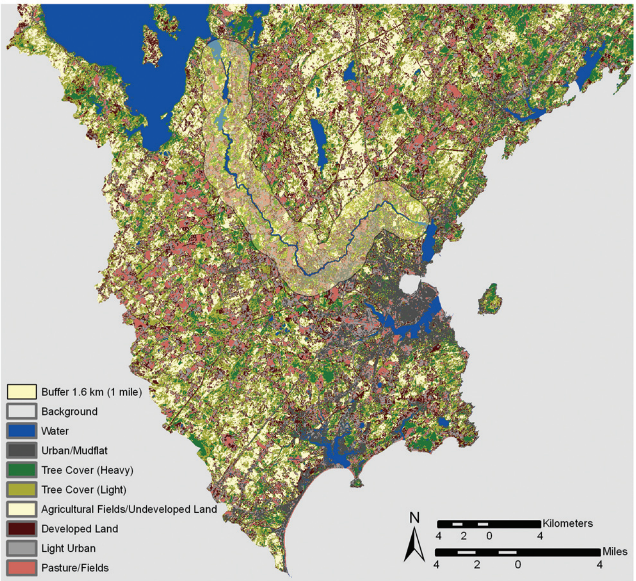


Figure 2. Land Use map for the Presumpscot River Watershed with a 1 mile Buffer

Land use classifications are effective at examining spatial patterns and arriving at quantitative summaries, but the results must be assessed against reference data to build confidence in the outcome. An accuracy assessment process using a stratified random sample of 80 points with 10 points per class is run to ensure coverage of all eight cover classes. Reference pixels are checked against high spatial resolution Google Earth imagery, 0.15 m aerial color digital orthoimagery and substantiated by extensive local knowledge. The results of the error matrix generated through the accuracy assessment indicate an overall classification accuracy of 82.5 percent. The Kappa index of agreement, which indicates the extent to which the assignment of pixels in the error matrix are due to 'true' versus 'chance' agreement, is reported at 0.78 (Lillesand, Kiefer, Chipman 2008). These statistics only refer to the sample of points used in the accuracy assessment versus the entire image and hence must be interpreted with caution. However, the reasonable overall accuracies provide confidence in the classification.

Land use class	Class composition	Area (ha)	Percent of total
Pasture/Fields	Open pastures, hay cultivation	6398.46	5.49
Light Urban	Low density urban use, sprawl	12799.71	10.99
Developed Land	Dispersed rural land uses, bare ground in rural areas	15432.57	13.25
Agricultural Fields/ Undeveloped Land	Fallow or planted agricultural fields	21391.83	18.36
Tree Cover (light)	Tree Cover (light)	29464.02	25.29
Tree Cover (heavy)	Heavy tree cover	13207.77	11.34
Urban/Mudflat	Mixed class of high density urban use, bare ground, impervious surfaces and mudflats along coast	7921.35	6.80
Water	Open water, rivers, lakes, ponds	9868.23	8.47
Total		116483.94	99.99*

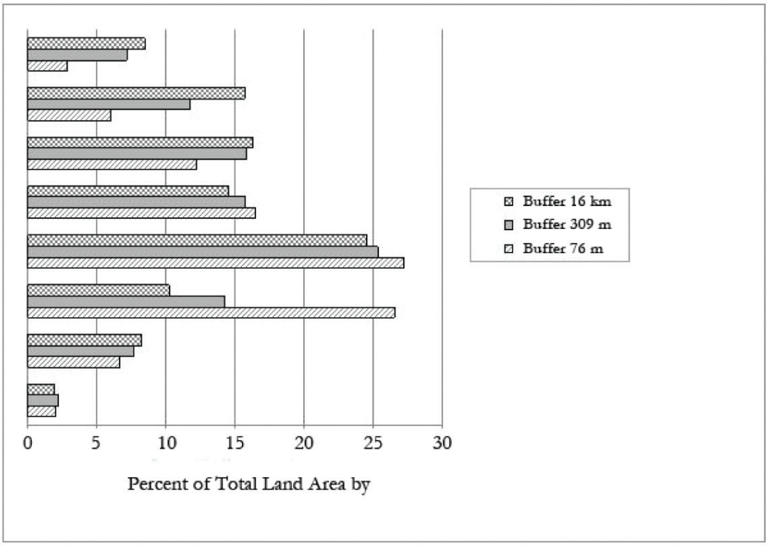
* rounding discrepancy

Table 1. Summary statistics for land use categories across Presumpscot watershed

A buffer analysis using 76 m (250 feet), 305 m (1000 feet) and 1.6 kilometers (1 mile) buffers is performed to assess the dominant land uses in these successive zones along the river (Fig. 2). In compliance with the Clean Water Act, many states have enacted laws to regulate land use within riparian and other shoreland zones. Maine's Mandatory Shoreland Zoning Act (MSZA) is case in point and requires a 76 m (250 foot) zone along major rivers where all development activities are closely monitored and require a permitting process (ME DEP 2008b). The 76 m buffer corresponds to MSZA, while the 305 m and 1.6 km (1 mile) buffers correspond to those used in other studies (Bentrup 2008, ME DEP 2008b). These buffers are used to assess the general land use trends and identify potential contaminants from nearby sources that might reach the river.

A cursory visual analysis of the FCC and land use map reveals a non-contiguous, fragmented riparian buffer of tree cover along the river from Lake Sebago to the town of South Windham. This buffer, however, rarely exceeds 250 m from either bank. As the river meanders south and east of South Windham, urban and agricultural activities extend all the way to almost the river's edge with limited room for a buffer. The total land area contained within the three buffer zones, while small, belies their significant biological and ecological services. Graph 1 shows the percent of land area by land use class for each of the buffers.

The pattern across all three buffers indicates a greater proportion of green space closest to the river, while Urban and Developed Land categories gain in proportion in the outer buffers.



Graph 1. Percent of total land area by buffer

As seen in Graph 1, tree cover categories comprise approximately 54 percent of the 76 m buffer, while the Urban, Light Urban and Developed Land classes make up approximately 24 percent. In the 309 m buffer, Light Urban, Developed, Urban and Pasture/Fields have all seen increase in their proportional coverage within the buffer to 34 percent, while tree cover categories observe a decline to just under 40 percent (Graph 1). Close to 40 percent of the 1.6 km buffer is dominated by urban and developed land classes. Most tellingly, the Light Urban category observes the most dramatic jump from 6 percent to almost 16 percent between the 76 m and 1.6 km buffers. Potential non-point pollution threats from impervious surface run-off to the Presumpscot from this zone will be significant. Agricultural non-point pollution sources upstream through overland flow or seepage into the water table would also make the river vulnerable to heightened nitrogen and phosphorous loading, erosion and sedimentation. Urban runoff contributions of suspended and dissolved solids, toxic organics, trace metals, and salt, sand and hydrocarbons off roadways are chief pollutants downstream (CBEP 1996). Studies indicate that even narrow buffers can significantly slow and help mitigate some of these pollutants (Mayer et al. 2005). The expansion of impervious surfaces with urban and suburban development, as is the case with this part of southern Maine along the lower Presumpscot, will no doubt exacerbate these issues.

Conclusions

In this paper we trace a history of use for the Presumpscot River and construct a land use map for its watershed examining the dominant land use activities that influence the health of this ecosystem. We particularly focus on a 1 mile buffer along the river to examine existing land uses and identify potential areas of concern. Our results indicate that industrial uses of the river have abated from their height during the twentieth century due to stricter regulation and the region's changing economy. However, threats from non-point sources and the expansion of impervious surfaces along development corridors remain issues of concern. The sustained pressure from development activities poses significant challenges to the river's health. Building protections for fragile ecosystems, such as buffers in this case, have aided in mitigating some of the stressors to river systems. Over time, Maine's MSZA has worked toward controlling land use activities and preserving much of the green space in the immediate buffer along the river. Such efforts often work in tandem with other laws to ensure further compliance and meet a state's broad environmental and habitat protection objectives. For example, the Maine Natural Resources Protection Act regulates the alteration of streams, rivers, ponds, etc. and consequently targets similar land features as the MSZA (ME DEP 2008b).

Remote sensing technologies allow us to examine and monitor dynamic landscapes shaped by coupled natural and human processes (Turner, Lambin, and Reenberg 2007). As with the Presumpscot, landscape changes can have far-reaching consequences for ecosystems and human populations. Systematic assessments using satellite data now provide us the ability to monitor land management needs and model longer-term impacts from specific land use activities. The importance of buffers in riparian protection is already well established in the literature (Dosskey 2001; Bernhardt et al. 2005). Increasingly, studies are employing remotely sensed data to assess buffer configuration, width and continuity in their ability to retain and attenuate non-point source pollutants. As higher resolution spatial data become more cost effective, these will provide even more detailed assessments of land use activity within buffer zones.

A buffer analysis such as the one completed for this study provides an assessment of the spatial configuration of land use classes within a river's riparian zone. Such studies can be particularly useful to state agencies engaged in monitoring long term changes and compliance efforts. Within the state of Maine, local municipalities, planning boards, as well as the Maine Department of Environmental Protection benefit from having such data when monitoring and regulating development activity along riparian zones and lake boundaries. Moreover, taking advantage of the repeat coverage provided by satellite data, such analyses can be completed periodically to assess dynamic changes occurring within buffer zones. The methodology applied in this paper can be replicated in similar riparian settings. It can strengthen our understanding of how buffers work, the efficacy of regulatory efforts, and contribute to our knowledge of human impacts and modifications of the environment.

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