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Multifunctional Riverscapes:
Stream restoration, Capability Brown's water features, and artificial whitewater

By

Kristen Nicole Podolak

A dissertation submitted in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy
in
Landscape Architecture and Environmental Planning
in the
Graduate Division
of the
University of California, Berkeley

Committee in charge:

Professor G. Mathias Kondolf, Chair
Professor Louise Mozingo
Professor Vincent H. Resh

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Abstract

Multifunctional Riverscapes

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Kristen Nicole Podolak

Doctor of Philosophy in Landscape Architecture and Environmental Planning

University of California, Berkeley

Professor G. Mathias Kondolf, Chair

Society is investing in river restoration and urban river revitalization as a solution for sustainable development. Many of these river projects adopt a multifunctional planning and design approach that strives to meld ecological, aesthetic, and recreational functions. However our understanding of how to accomplish multifunctionality and how the different functions work together is incomplete. Numerous ecologically justified river restoration projects may actually be driven by aesthetic and recreational preferences that are largely unexamined. At the same time river projects originally designed for aesthetics or recreation are now attempting to integrate habitat and environmental considerations to make the rivers more sustainable. Through in-depth study of a variety of constructed river landscapes - including dense historical river bend designs, artificial whitewater, and urban stream restoration this dissertation analyzes how aesthetic, ecological, and recreational functions intersect and potentially conflict.

To explore how aesthetic and biophysical processes work together in riverscapes, I explored the relationship between one ideal of beauty, an s-curve illustrated by William Hogarth in the 18th century and two sets of river designs: 18th century river designs in England and late 20th century river restoration designs in North America. I used two quantifiable variables, sinuosity and symmetry, to compare the ideal curve of beauty to the designed river curves. Hogarth's s-curve and river restoration meanders had symmetrical curves. Symmetry in restoration designs represents a theoretical condition and is counter to how most natural rivers meander. A second aesthetic-ecological study examined whether 18th century English landscape design represents design with nature. By tracing the persistence of Capability Brown's river designs over the past two centuries, the results show Brown's designs required maintenance and are not self-perpetuating as expected of a design based on natural processes.

To evaluate the intersection of recreation and ecological functions, I conducted a case study of three urban river projects, a historical study of artificial whitewater designs, and an observational study of summertime whitewater park use. By comparing the ecological and social impacts of three urban river projects (Cheonggyecheon in Seoul, South Korea, the South Platte Greenway in Denver, United States, and the Isar River in Munich, Germany), one emerged as moving towards

multifunctional planning and design. The Isar River project was unique because the planners and designers used a dynamic guiding image, gave the river room to roam, and allowed some dynamic biophysical processes to occur. The selection of the guiding image for the Isar restoration was fortuitously a publicly valued stream reach for its aesthetics and existing recreational use. The South Platte Greenway, which contains a whitewater park, illustrates a riverscape made primarily for recreation. The history of artificial whitewater designs evolved since the 1970s to a point in 2000 when the Sydney Olympic Whitewater Course was disconnected from a stream to create a fair playing field for competitors where all of the whitewater variables could be controlled. Meanwhile, instream whitewater parks began to include habitat and fish passage considerations in the engineered wave structures. Observations of whitewater park use and surveys of park user's perceptions of the parks revealed that kayakers represent only a small fraction of park users and overall use evinced no clear relationship to streamflow but varied with air and water temperature. Summer streamflow provisions for whitewater parks potentially limits the diversity of instream users and the ecological function. While whitewater park users value clean water as the most important characteristic, all interviewed park users wanted the park to have a natural appearance, but they did not mind seeing concrete in the river.

Understanding the patterns of recreation and perceptions of rivers in relation to biophysical processes such as streamflow or channel pattern is fundamental to achieving sustainability. The forms that people prefer—perhaps because they are beautiful—and a local-level understanding of recreational use need to be considered alongside the physical and ecological patterns and processes of rivers, the domain of landscape ecology and river science. Combining ground level research and perception studies with environmentally based landscape planning can create multifunctional landscapes. For previously impacted rivers in developed areas, multifunctional riverscape planning and design offers a sustainable development solution.

DEDICATION

This dissertation is dedicated to my parents, Tina and Bob Podolak, who instilled in me a love for rivers.

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Chapter 1

Multifunctional River Planning and Design

1.1 Introduction

From the earliest civilizations until today, people sculpted water into pools, lakes, fountains, and other water features. The effect of calm water on a horizontal plane can be contemplative and hypnotic, while falling water or water shooting up from a jet can generate excitement (Nasar and Lin 2003, Burmil et al. 1999, Whalley 1988). Water bubbles, sprays, reflects, and flows in a visually mesmerizing way. It trickles, roars, and drips to focus our attention or block out surrounding noise. We interact and perceive water using all of our senses, and water is intriguing. As landscape architect Lawrence Halprin (1963:134) said: "Even in the city, the sound and sight of water stirs the most elemental and basic roots of our human interest." William Whyte (1980) wrote about water in his book *The Social Life of Small Urban Spaces*; one of the best things about water is the look and feel of it, and it was not right to put water in front of people and then keep them away from it. Mark Treib (1987) described water in landscape design as evoking a solvent, mirror, axis, illusion, meander, extravaganza, pencil, and sonic mass. These descriptions provide a sense of how the water looked, sounded, and flowed in various water designs.

To reverse past environmental impacts on river and to improve ecosystems and human quality of life, river restoration projects have become widespread, with over 37,099 documented in North American by Bernhardt et al. (2005), who found that evaluation of restoration success is often based on site observations or positive public opinion (47% of projects). Improving stream aesthetics, recreation, and educational opportunities are common goals in river restoration efforts; however, goals vary widely from urban to wilderness environments with different opportunities and constraints, depending on the setting (Bernhardt et al. 2005, Kondolf and Yang 2008). There is more money spent on river restoration in urban areas than elsewhere (Bernhardt et al. 2005). In Maryland, for example, about thirty percent of the river restoration projects from 1995-2005 were in cities, and four counties with the densest populations spent half of all the restoration funds (Hassett et al. 2005). Some river restoration designs, especially those in constrained urban environments may resemble instream gardening more than ecological restoration (Kondolf and Yang 2008, Bernhardt and Palmer 2007). Yet, even gardening can reconnect people with nature. Whalley (1988) said: "Landscape architecture… is a dimension of nature added to planning… a properly balanced relationship between people, plants, nature." In urban areas, streams that had mono-functional designs for flood control, such as the Los Angeles River in California, are being re-envisioned today in terms of multifunctionality including some degree of ecological restoration.

The most recent trend is incorporating multiple functions such as habitat improvement, recreation, aesthetics, water quality, and flood control into river restoration and greenway projects (Schanze et al. 2004, Otto et al. 2004, Searns 1995, Ahern 1995). According to Hellmund and Smith, "single-goal greenways are difficult to defend and should only rarely be proposed" (2006:222). The era of greenways with single functions such as recreation is over. Even when a planner or designer creates a recreational greenway they still need to take, "responsibility for protecting broader landscape integrity" (Hellmund and Smith 2006:219). On the other side, greenways should not solely focus on habitat if compatible forms of recreation or other social goals are possible (Hellmund and Smith 2006). In the past, landscape architects focused on aesthetics and recreation in cities, now they are increasingly including ecological objectives, even in megacities, as part of the bringing nature into the city movement (Schanze et al. 2004, Tunstall et al. 2000). The acceptance of nature in the city is still a matter of how it fits to a preconceived set of values and how much it is controlled (Hough 1995). Planners and designers can determine ways to balance aesthetic and recreational preferences with dynamic stream processes to make multifunctional riverscapes a reality.

Multifunctionality in planning and design comprises the idea that social and ecological function can be accommodated in the same space at the same time and forms an important cornerstone of sustainable development (Lovell and Johnston 2009, Brandt and Vejre 2004). River restoration typifies the pursuit of multifunctional landscapes where different disciplines must come together for designed ecological solutions that provide multiple benefits in contrast to degraded landscapes. Multifunctionality is an idea expressed in landscape-ecological planning and greenway planning. The abiotic-biotic-cultural (ABC) model helps illustrate the evolution underway towards a multifunctional planning approach where the different functions are all accomplished (Figure 1, Ahern 1995). However, the actual guidance for the planning and design of a stream as it relates to people's use and ecological improvement is incomplete. There is a gap in understanding the conflicts and synergies that exist between multiple functions, and an emphasis on geo and bio-ecological approaches (O'Farrell et al. 2010). What is missing is an understanding of the cultural side of restoration and enhancement alongside the geological and ecological. While landscape ecologists can provide biophysical understanding of how and where habitat restoration should proceed, the scientific understanding is not sufficient for the planner interested in bringing together biodiversity, recreation, and aesthetics. Further, the ecological approach to habitat planning and design is not usually applied in an urban context (Potschin and Haines-Young 2006, Ahern 2007).

This study contributes to the literature by providing insight on the intersection of cultural and ecological functions in riverscape planning and design. The premise is that riverscapes can incorporate multiple functions through environmental planning and ecological design. The idea of multifunctionality is important because there are many threats such as the urban stream syndrome and many opportunities for improving recreational access and riverscape aesthetics. The urban stream syndrome encompasses various sources of ecological degradation and channel changes that occur when basins become urbanized (Paul and Meyer 2001). The effects include increased peak flow and shorter lag times leading to river incision and channel widening; increased water temperature, loss of floodplains and aquatic habitat, and conditions that only support tolerant species (Leopold, 1994; Dunne and Leopold, 1978, Gurnell et al. 2007, Walsh et al. 2005, France 2002).

Riverscape planning and design is a visible reflection of culture and its values as they change over time. Multifunctionality in riverscapes deserves attention to understand whether this approach will promote sustainable development by improving the urban stream syndrome and nature deficit disorder. Through studies on a variety of riverscapes, including river restoration, historical serpentine lakes and river bends, and artificial whitewater, this dissertation advances the understanding of conflicts and synergies in multifunctional riverscape planning and design. Specifically, I focus on the aesthetic, recreational, and ecological functions in riverscapes. First, I discuss how river projects are evaluated and past studies addressing social and ecological function. Then, I describe the individual studies and how they address the multifunctional riverscape question. Finally, I briefly review past studies on river aesthetics, ecological planning as it applies to riverscapes, and studies integrating river recreation and ecological function in planning and design.

1.2 Problem Statement

Stream restoration relies on scientific understanding of stream to guide restoration, but it is fundamentally a social endeavor with human values influencing the objectives. Positive public opinion and not scientific criteria often form the basis for assessing the success of stream restoration efforts (Bernhardt et al. 2005). In a study of 37,000 river restoration projects in the U.S., Bernhardt et al. (2005) found 47% of projects judged success based on how natural the river looks during site visits and in photos, and on positive public opinion. Essentially, these measures of success depend on how attractive and inviting the new constructed river is following project completion (Junker and Buchecker 2008). Aesthetic improvement or an aesthetic yearning, increased recreational access, and urban development may underlie aspects of stream restoration even when science justifies the designs (Downs and Kondolf 2002). Restoration guidelines and river planning usually focus on ecology or aesthetics or recreation, but rarely describe ways to integrate the multiple functions.

A few exceptional studies combine ecological function and cultural values using indicators of success. Fry et al. 2009 developed metrics that spanned the fields of landscape ecology and landscape aesthetics to try and integrate human and ecological benefits. Schanze et al. (2004) evaluated twenty-three urban river projects in Europe using eco-morphological and social indicators, Woolsey *et al.* (2007) evaluated restoration of the Thur River in Switzerland using forty-nine indicators and thirteen classes of objectives, Saraiva *et al.* (2008) gathered together fifteen experts who established 177 indicators of restoration success grouped into 5 dimensions: ecological/environmental, spatial/urban, psycho/social, economic, and institutional/governance. A challenge of this research approach is selection of indicators from the numerous sets of possible indicators. Another issue is not being able to compare projects with different sets of indicators. Finally the indicators reflect the cultural values of a specific place. The approach functions like a checklist with few clear lessons for planning and designing multifunctional river projects.

Additionally, a few exceptional studies adopt a trans-disciplinary, multi-method approach. A recent one by Chiari *et al.* (2008) integrated habitat mapping of birds sensitive to restoration and recreational disturbance with mapping of human use and interviews and surveys of river users. They found the river project studied did not take into account the intensity, distribution, or range of recreational use of the river. An older study on hedgerows (Burel and Baudry 1995) surveyed the local population to identify reactions to landscape change (i.e. hedgerow removal and management) and characterized the landscape units in terms of sensitivity to change. They concluded that hedgerow network management is important for ecological and historical value in greenway planning. This dissertation takes a similar socio-ecological approach to identify conflict and synergies between human values and ecological function.

1.3 Outline of Chapters

This dissertation consists of five independent research chapters. Chapters 2 and 3 address historical riverscape designs by Capability Brown, originally envisioned as aesthetic improvements to the landscape. Chapter 2 asks the question do they represent design with nature? Chapter 3 tests the connection between Brown's riverscape and William Hogarth's historical aesthetic theory on beauty, and recent channel realignments for river restoration. This chapter delves into the unacknowledged aesthetic influence on channel meander design. Chapters 4-6 analyze recent urban river projects and artificial whitewater. The three urban river projects in chapter 4 all attempt to combine improved ecology, recreation, and aesthetics and I evaluate the planning and design approaches. Artificial whitewater is a new type of river design where drop structures activate the water and form hydraulics such as waves and holes. I compile a brief history of designs in chapter 5 then report the results of an observational study on the recreational use and perception of the whitewater in chapter 6. I compare the use patterns and user values with the potential ecological impacts of the design.

In chapter 2, I evaluated the similarity between William Hogarth's eighteenth century aesthetic theory on beauty with two sets of river designs: eighteenth century serpentine lakes and river bends designed by Capability Brown and twentieth century river restoration designs. Hogarth's illustration of the line of beauty provides an ideal s-curve that can be compared with the river designs by Brown and river restoration practitioners. I first describe the different methods of design and construction used by Brown and river restoration designers. I then characterized the form of the curves by measuring the sinuosity and symmetry of the line of beauty and comparing it to the river designs. Sinuosity is a measure of curvature and values close to one indicate a straighter line. I found the sinuosity of Brown's river designs matched the line of beauty (mean S=1.2), but Brown created a variety of forms ranging from single bend lakes to straight lakes and s-curved lakes. His method of damming streams probably limited his ability to make an exact form and he may have been employing some of Hogarth's other principles of beauty. River restoration designs were more sinuous than the line of beauty (mean S=1.4), and the difference compared to Brown's designs was significant. Both the river restoration designs and the line of beauty had almost perfect symmetry. The findings indicate that the sampled river restoration designs do exhibit an aesthetic element in the symmetry and single channel form, despite being science-based. Even the scientific illustrations of meander dimensions tend to be highly symmetrical despite research showing that rivers are asymmetric or alternate between ordered, low sinuosity, and chaotic, high sinuosity reaches. Although this study is limited to two readily quantifiable variables, sinuosity and symmetry, it is the first to examine the form of an aesthetic theory in relation to classic river design and recent river restoration design.

I continued researching Capability Brown's water features, which are often portrayed as naturalistic or design with nature, by assessing how they have lasted through time in chapter 3. I traced the persistence of Brown's water features using historical and recent maps, aerial photos, and satellite imagery. McHarg (1969) and others portray eighteenth century English landscapes as examples of designing with nature and self-perpetuating. Through analysis of original plans, historical topographic maps, and current satellite imagery, I documented the persistence of

Capability Brown's water features. I assessed the underlying geology of each site to determine if Brown accounted for local sediment yield rates in his designs. I expected that sites in the glaciated northwest, where river systems are more active, would fill with sediment more quickly than sites in the southeast. I interviewed estate managers to determine the maintenance requirements of each water feature. Out of a sample of 53 water features, I found 37 (70%) exist today as Brown planned them more than two centuries ago, a better survival rate than enjoyed by the surrounding landscapes. However, the persistence of the water features is largely attributable to periodic maintenance: out of 27 estates responding to our inquiries, 18 (67%) reported dredging or vegetation removal to maintain the water features. I did not find evidence that Brown accounted for local sediment yield rates in his designs, nor did I find different patterns in sedimentation or dredging histories of the water features as a function of geologic region. Although Brown's water features may look natural, they survive because of significant human intervention. Given contemporary interests in managing for habitat and restoration, the current management regimes require consideration of both historic preservation of iconic elements of the English landscape and ecological conservation values.

Chapter 4 addresses urban river restoration, sometimes described as instream gardening or green pipes, implying little ecological value. This chapter addresses the question; to what extent do urban river restoration projects actually restore the ecology versus simply create attractive public spaces? To answer this question I compared three high-profile urban river projects based on an assessment of their stated objectives and standards for ecologically successful river restoration. I found that while the Cheonggyecheon stream in Seoul, South Korea, supports fish, and in places creates the illusion of "nature," it is best viewed as a fountain because of its artificial water source, steady flow, rigid banks, and impermeable bed. The South Platte River in Denver, Colorado, focused on recreation without significantly reversing degradation of the river's ecological functions. By contrast, the works on the Isar River, in Munich, Germany, combined ecological restoration with enhanced recreational opportunities and aesthetics. All three projects serve as a human amenity, but the Isar pushed traditional aesthetic ideals of nature into a new realm, and allowed people to find pleasure in connecting with the river, while giving it room to evolve naturally by way of sedimentation and erosion processes.

In chapter 5, I present the history of artificial whitewater. Today, more than one hundred artificial whitewater designs exist, seven of which are Olympic venues, yet the history of these designs had not previously been documented. This study traces the design evolution through an inventory of sites, 28 qualitative interviews with designers, coaches, and athletes, and comparison of the level of difficulty (i.e. level of kayaking skill required to navigate) of 55 designs using a quantitative index based on design dimensions. The first designs in 1972 were for the Olympics or training sites for Olympic hopefuls. Soon after, whitewater designs replaced hazardous water infrastructure and were seen as urban park assets. In the 2000 Olympic games a major shift occurred when the first recirculating whitewater course with no connection to a stream was made in Penrith, Australia. During the same time period, a new discipline of paddling called freestyle emerged and artificial whitewater designs shifted towards surfing features. Some cities in Colorado with instream whitewater parks acquired controversial water rights for recreation in the 1990s. These water rights and the spread of whitewater parks throughout the U.S. lead to increasing environmental review and more sophisticated instream designs to accommodate fish passage and recreation in the same drop structures. Since the 1970s the designs evolved towards greater control over the hydrology to create a fair playing field for competition and to make whitewater more reliable, safe, and convenient.

In chapter 6, I report the results of observations of summertime whitewater park use and surveys of park visitors to understand whether people's perception of the parks fits with ecological considerations and how their use related to physical factors such as streamflow. The results indicate that engineered river parks originally designed for kayaking, serve summer beach functions for families in cities—and this use is more important in terms of total number of users and impact on underserved communities. Visitors ranked clean water, a natural appearance, and the sound of water as the most important park attributes and did not object to seeing concrete in the river, suggesting a disconnect between perceived naturalness and actual ecological function. The biggest factor determining daily park use is the air temperature, as it gets hotter more people visit, and as the water temperature warms up more people get into the river. There was no relationship between use and streamflow as expected based on past studies.

The conclusion synthesizes the five chapters, identifying conflicts and synergies between aesthetics, recreation, and ecology, and offering ideas on how to further advance multifunctional planning and design.

1.4 Past studies on river planning and design

Before launching into the first study, it is constructive to review past studies on river planning and design. These provide the theoretical framework for this cross-disciplinary research. I first review studies on the aesthetics of rivers and water features by landscape architects and surveys evaluating the viewers' preferred river or water scenes in photos. Next, I review landscape ecological planning as it applies to riverscapes and describe a few studies that integrate river recreation and ecological function in planning and design. This review addresses studies relevant to this research does not exhaustively cover any of the individual subject areas.

1.4.1 Aesthetics

Landscape architects have studied the aesthetic preference for constructed water features and natural streams to determine how to design future water features and to prioritize natural rivers for protection from development. They also observe how people play in water fountains and streams to improve the design of water features so they support recreational use. To enhance the human connection with rivers, some designers and planners try to incorporate an aesthetic and recreational use component into instream infrastructure (low head dams, water diversions) and modifications to streambanks such as levees, riprap, willow bank stabilization (Litton 1974, Manning 1997, Otto et al. 2004). A recently designed river features is whitewater parks with waves engineered to improve safety of low-head dams in streams and provide a place to surf or watch the flowing water. Another example is Litton's (1974) recommendation to design stream levees to provide aesthetic and recreational benefits in addition to the primary flood control purpose. With recent water quality improvements in developed countries, planners and designers should strive to reconnect people with urban streams. There are two main approaches to riverscape quality assessment: expert based views of the landscape employing abstract formal aesthetic terms and perception surveys based on environmental psychology pioneered by Kaplan and Kaplan (1989). Both approaches address landscape quality as an interaction of biophysical processes and human perception and experience.

An example of expert based views on the aesthetic and recreational quality of rivers were studies conducted in the late 1960s when the federal government began to designate rivers for protection from development under the Wild and Scenic Rivers Act of 1968. This Act stated, "outstanding remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values, shall be preserved in free-flowing condition" (90 U.S.C. §542). To determine which rivers to protect, researchers developed qualitative and quantitative methods to assess the riverscape quality and uniqueness. Luna Leopold a fluvial geomorphologist and hydrologist was one of the first to attempt to quantify river aesthetics (Leopold and Marchland 1968). He developed a rating system for geomorphic, ecologic, human use, and human-interest variables in forty-six categories to determine if the Hell's Canyon section of the Snake River in Idaho was unique aesthetically compared to other western rivers. The study concluded that the river was unique and deserved protection under the Act.

Leopold's expert opinion was subjective and his own aesthetic preferences probably influenced the analysis. For example, he preferred whitewater streams, because a small river "tumbling over a succession of falls are more impressive or are more aesthetically appealing than a large river which appears sluggish" (Leopold and Marchland 1968:10). Another preference for single thread meandering channels appears to exist in observations of stream patterns and river restoration designs. Dunne and Leopold (1978:625) described meandering channel patterns as "the beautifully regular ribbonlike bends so often seen when traveling by air", but did not comment on the aesthetics of straight or braided streams. In North American stream restoration designs where the channel is realigned the practitioners often design a meandering channel with s-curves in place of formerly degraded river reaches (Kondolf 2006).

In *Water and Landscape*, Litton et al. (1974) identified three aesthetic criteria for evaluating the beauty of water in the landscape: unity, variety, and vividness. He made observations of wilderness rivers in the western U.S. (Snake River, North Platte River, Wind River, and Yellowstone River in Wyoming, White Cloud Range tributaries and Germania Falls in Idaho) and the photos throughout the book emphasize this focus. Litton et al. (1974) described variety as the richness or diversity in the movement, color, and edge of the riverscape. Human impacts tend to move in the direction of eliminating variety. Variety has the added benefit of being potentially ecologically beneficial as well. For example, the stream pattern can have variety "in different reaches from meanders to straight stretches–with all stages between the two and in various relationships to one another" (Litton et al. 1974:108). Unity is a term describing how water as a liquid material provides coherence in a stream or lake, and gives consistency to different parts of a whole. Vividness is the juxtaposition of different water features adjacent to one another, such as a plunge pool below a waterfall. No single criterion is isolated or adequate by itself, the three work in concert. According to a study of aesthetics in environmental planning, Litton et al.'s method provides "the decision maker with information which show precisely how human use or man-made facilities enhance, are compatible with, or degrade the visual landscape, thus offering a very useful tool for environmental planning" (Redding 1973:74). He identified the importance of the surrounding landscape or landforms in shaping the river's character and this was similarly concluded in perception studies where a gorge landscape ranked higher than an open waterscape of the plains (LeLay et al. 2011).

Perception studies use visual surveys or recreational user surveys to assess different river or water characteristics. A study on the perception of water features in urban plazas used photographs of five different water features: still, flowing, falling, jet, and combination of moving water to evaluate people's preference and the calming or excitement effect on feature on the viewer. Jets are features where the water rises to a high elevation, as in a fountain jet and can be single stream, sprays, or aerated (Nasar and Lin 2003). The study found that people prefer moving water and combinations of moving water to still water (Nasar and Lin 2003). In another photographic survey of seventy different stream views, Herzog (1985) found that people prefer a mountain waterscape to swampy areas of stagnant creeks, and spaciousness or the long view across water. Bulut and Yilmaz (2009) asked more than one hundred university students to rank six waterscapes in a survey. They found that urban waterscape scenery was the most preferred, second was waterfalls in rural scenery, and third was standing water scenery (Bulut and Yilmaz 2009). In the study, students ranked urban water features with easy access and one's that looked usable for recreation as the highest of all (Bulut and Yilmaz 2009). A study by Mosley (1989) found that anglers did not like urban river scenes because of the traffic and structures. On the other hand, members of the public highly valued a river scene with orderliness such as urban rivers in parks or residential settings (Mosley 1989).

Studies on river perception reveal that people prefer a "natural" appearance (Junker and Buchecker 2008, Gobster and Westphal 2004), a medium water level (Whittaker et al. 2005), and trim riparian vegetation to avoid creating places for burglars to hide (Purcell 2006). They do not like large wood in the channel (Chin et al. 2008, Le Lay et al. 2011), they prefer a dominant view of water not gravel sediment (Le Lay et al. 2011) and stable streambanks (Kondolf 2006, Wohl et al. 2005). A study of urban stream greenways in Japan concluded that recreational use most influenced people's perception of streams (Asakawa et al. 2004). Finally, people judge the river water suitability for swimming based on color and knowledge of the cause of the water color (Smith et al. 1995). Turbid water with a blue color is seen as suitable while brown water is only seen as suitable if the viewer is knowledgeable about the source of the color from natural humic staining (Smith et al. 1995). The perceptions may differ regionally; for example, in Germany, Oregon, and Sweden there is more acceptance of large wood than in China where the attitude is that large wood needs improvement through channel correction (Le Lay 2011). Additionally, some studies provide detailed information on the perceptions, as in the example that people prefer large sized sediment to small sediment with differences amongst groups of participants reflecting different interests (Le Lay 2011). People are attracted to a bend in a path or a river meander bend because it has a sense of mystery that "encourages one to enter and to venture forth" with the promise of further information beyond what is visible from the starting point (Kaplan and Kaplan 1989:55). These studies, while informative, only address the visual appreciation of riverscapes and do not address the other senses: hearing, smell, or touch/feel which all influence river perception.

Junker and Bucheker (2008) assessed how the aesthetic preferences of the public related to the eco-morphological quality of three different river restoration scenarios presented in manipulated photographs. Experts assessed the eco-morphological quality. People valued the more eco-morphologically valuable river designs. This result suggests that the public will view river restoration aimed at ecological restoration positively. The photo comparison included one entire set with infrastructure for recreation and leisure. Only at the lowest level of eco-morphological quality was the recreational infrastructure viewed positively, from which Junker and Buchecker (2008:15) concluded, "If people do not perceive a scenario to be particularly natural, then they wish at least to have easy access to it." In addition to the aesthetic ideals of rivers, there are important ecological functions, which can be identified and enhanced through ecological planning and design.

1.4.2 Landscape ecology

Several scholars, landscape architects and landscape ecologists, suggest specific ways to create multifunctional urban river corridors. Landscape architect Ian McHarg described the idea of multifunctionality in his influential book *Design with Nature* (1969) in an ecological planning exercise for multiple land use in the Potomac Basin. He said the objective was to find the "highest and best uses of all the land in the basin" and identify "the maximum conjunction of these" (1969:128). The result is a matrix of compatible land uses spatially laid out across the entire Potomac River Basin. He extended the analysis to the urban core of Washington D.C., the capital. Here McHarg identified the physiographic and ecological expression of the city to guide any future efforts to maintain the existing continuity or recover and enhance it. Interestingly, the Potomac and Anacostia Rivers that frame the city along with Rock Creek and Goose Creek (now called Tiber Creek) are the highest-ranking features of natural identity (Figure 2). These two rivers and creeks McHarg considers "the major system of open spaces" (1969:183). Today, there is a large river restoration project underway on the Anacostia River to improve the stormwater management, recreational space, water quality, and habitat (fish passage and riparian reforestation)(DDOE 2008). This project is an example of planning and designing a riverscape to enhance the natural identity, and idea proposed by McHarg fifty years earlier.

Richard Forman, a landscape ecologist and planner wrote about the importance of recognizing the difference between the spatial patterns of nature and people's design patterns in the book *Ecology and Design* (2002). The main difference is that nature produces forms and shapes that are curvy, aggregated, variable, irregular, dendritic, and convoluted. Human made forms are regular, straight, geometric, grids, and circles. He observes that form determined function and vice versa, and the functioning of the two types of design, human-made and natural, is different (Forman 2002). Human-made forms that intersect with nature require maintenance to keep the form. He prioritizes four indispensable spatial patterns in nature that should be prioritized in all planning and design projects: a few large natural vegetation patches, major vegetated stream or river corridors, connectivity between patches, and small patches in the surroundings (Figure 3). These are the most important because there is no technological substitute for the ecological values they provide. He promotes integrating culture and environment, but says to first design the ecological base and then enhance the aesthetics and economics (Forman 2002). Unlike McHarg whose planning is aligned with ecosystem services, Forman is focused more on ecosystem integrity with less emphasis on human services provided by habitat patches.

Hellmund and Smith (2006), landscape design and environmental science professors described the dual ecological and social dimensions of urban river planning and design in their book *Designing Greenways: Sustainable landscapes for nature and people.* In the same sense that a landscape ecologist uses patches to describe wildlife habitat, they discuss patches of human habitat such as a gentrified section of a riverbank where property values differ from the surrounding matrix. They discuss the need for diversity and rhythm in river trail design to, "take advantage of topography or local ecological and cultural features" (2006:191). They illustrate this idea showing the difference between a straight trail alongside a river and a meandering trail that intersects a historic site on a hill and a forest adjacent to the river (Figure 4). They identified Phil Lewis Jr., a landscape architect working before McHarg, as developing the planning of river corridors as recreational spaces and havens for biodiversity. Lewis overlaid transparent natural resource maps and found that areas along waterways held the bulk of the resources that were valued by the local people. Lewis identified resource nodes where ecological and cultural values overlapped and used these to guide planning. The corridors became the basis for a statewide trail system and a state land acquisition plan in Wisconsin.

In Manning's *Design Imperatives for River Landscapes* (1997), he analyzes the aesthetic and recreational components and their interrelation with natural processes, especially those involving the complexity and diversity of river alignments and edges. Manning describes three main aesthetic elements in river designs: the river itself with its "sense of journeying", the scenery which shaped and was shaped by the river, and the margins along the river that provide for human uses. It is along the margins where Manning emphasized the importance for ecological science because these areas are where two habitats intersect and complex interactions occur. Manning summarized the idea when he wrote: "the edges of water are potentially the richest zones of all, in human as well as natural terms" (1997:69). Finally, contemplation of rivers and the landscape are not enough and people, especially children, want to touch the water and challenge themselves. Manning (1997) recommends that streams be designed with complexity: curvature that would occur naturally, not just new meanders, gradients of vegetation where people have difficulty traveling, and vegetation to create varying viewpoints to allow nature and people to mingle effectively. Manning believed that, "We must never allow the construction or refinement of human focal zones to exceed requirements, or intrude into extensive zones of natural potential. Everywhere and always, in whatever special situation, we must respect the logic of gradients, seeking to enhance richness and diversity without confusion or conflict. This is the path to an optimum balance of human, aesthetic, utilitarian and natural values in the landscape of rivers" (Manning 1997:93, Figure 5).

1.4.3 River recreation and ecological function

In *Design for Outdoor Recreation* Bell (1997) presents the Recreation Opportunity Spectrum (ROS) that correlates recreational opportunities with the landscape setting from primitive to urban. Recreational waters in the city are intensely designed and managed and the recreational user is not seeking challenge or risk (Bell 1997). Bell (1997) addressed the issue of natural erosion along streambanks and suggests that recreational places be located on the inside of the bend to avoid causing damage. He focused on the streambanks: facilities adjacent to the water, and prevention of damage from recreation to the edges of the water where it meets the land. He recommended planning to separate different uses such as isolating fishing, swimming, and boating to prevent conflicts between user groups and because they require "particular qualities for river water depth, speed, or riparian vegetation" (1997:161). Otto et al. describe how to balance recreation and public access to urban rivers with river protection in *Ecological Riverfront Design* (2004), but they only address overly wide trails, motorized boating, and human health issues from exposure to poor water quality in urban rivers.

Kondolf and Yang (2008) reviewed how specific elements of a stream could encourage spontaneous recreational use. Spontaneous uses such as skipping rocks and swimming are more difficult to quantify than fishing or boating in a quantitative cost-benefit assessment, but could be equally important for the freedom and learning of children. Through systematic field observations of children's use of streams in Japan and California, along with surveys and children's illustrations of rivers, Yang (2004) gained insight on how to design for spontaneous use. She characterized spontaneous use as free of equipment (fishing poles, kayaks), close-by (no driving required), human-powered, and free from time constraints. She identified dirt paths along the stream with few other recreational users, a swinging rope above the water, and metal culverts as popular adventure places for children. She suggested streambed and bank forms that support spontaneous use, for example, a deep pool in combination with a bridge or rock outcrop creates a circuit where children can jump into the water and climb back out repeatedly. An overhanging bank provides children with an opportunity for observing and catching aquatic insects and fish, while stepping-stones form a stream crossing (Yang 2004). The focus in this study was social with little consideration of the ecological function.

Studies on the motivations and experience of whitewater paddling conclude that it is a way to escape the routine of everyday life and experience challenge and excitement (Fluker and Turner 2000). The extent, size, length, and difficulty of the whitewater are variables that most influence the experience of whitewater rafting (Herrick and McDonald 1992). Two studies on recreational use of three streams in Great Smoky Mountain National Park (Little River at Townsend Wye, Tennessee; Deep Creek at Deep Creek Campground, North Carolina; and Bradley Fork at the Smokemont campground, North Carolina)(Larson and Hammitt 1981), and the Upper Pemigewasset and Swift River Drainages in New Hampshire (Glass and Walton 1995) found that instream use was greatest in the afternoon on sunny, summer weekend days. Based on this finding the researchers recommended management strategies to reduce user conflicts and negative impacts to aquatic habitat, specifically salmon holding pools.

Studies on how instream recreational quality related to streamflow report an increased quality with increasing streamflow to a point, and then decreased with further increases, described as an inverted-U relationship that varies by location, skill level of the recreational user, and the type of recreational use (Brown et a. 1991, Whittaker et al. 2005). Recreational users willingness-to-pay for the maintenance of instream flows increases with flow up to a point, and then decreases for further increases in flow (Brown et al. 1991). The critical level differs by recreation activity. Anglers prefer lower flow levels than floaters and streamside users (Loomis 1987). Streamflow also has an aesthetic impact with quality diminishing at both flood stage and lowest flow stages (Litton et al. 1974). Too much flow covers the movement of water in riffle-pool sequences and hides both islands and sandbars. Too little water gives the impression of a uniform, monotonous flow, and diminishes the vividness because of the loss of whitewater.

These past studies on riverscape aesthetics, ecological planning, and recreation and ecology illustrate the diversity of fields and functions in riverscape planning and design.

Landscape architects and river scientists focused on characterizing the aesthetics of rivers and utilized surveys of public preferences in river landscapes. Planners and landscape ecologists approach riverscapes from a larger scale aerial view and discuss integrating multiple functions in land use. These landscape ecology approaches to planning streams sometimes integrate in aesthetics and recreation as evident in greenway planning and design, which has a smaller site or river reach scale perspective. However, often the focus is on protecting patches of habitat from development and linking these patches on a larger scale. In terms of recreation and ecology studies, the most overlap occurs in streamflow levels. Streamflow provisions for recreation may correlate of conflict with ecological flow regimes. In the following chapters, I evaluate how aesthetic and recreational uses intersect with ecological planning and design.

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Figure 1. Leitão et al. (2006) illustrates the abiotic-biotic-cultural resource continuum in landscape planning and how different disciplines of planning fit into the continuum.

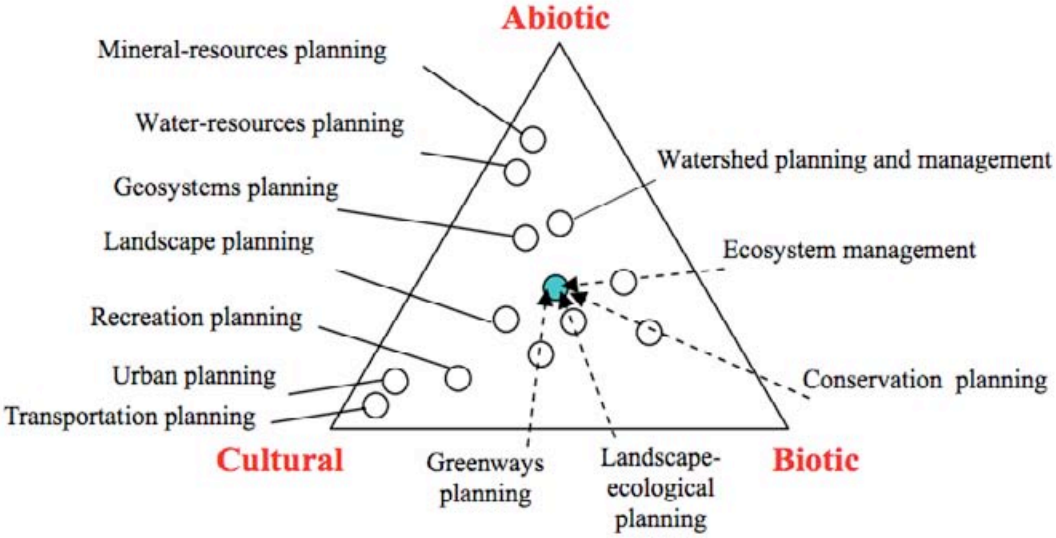


Figure 2. Ian McHarg's (1969, 185) analysis of physiographic and ecological elements in Washington, D.C. reveals the highest-level natural identity in the Potomac River, Anacostia River, Rock Creek, and Goose (Tiber) Creek.

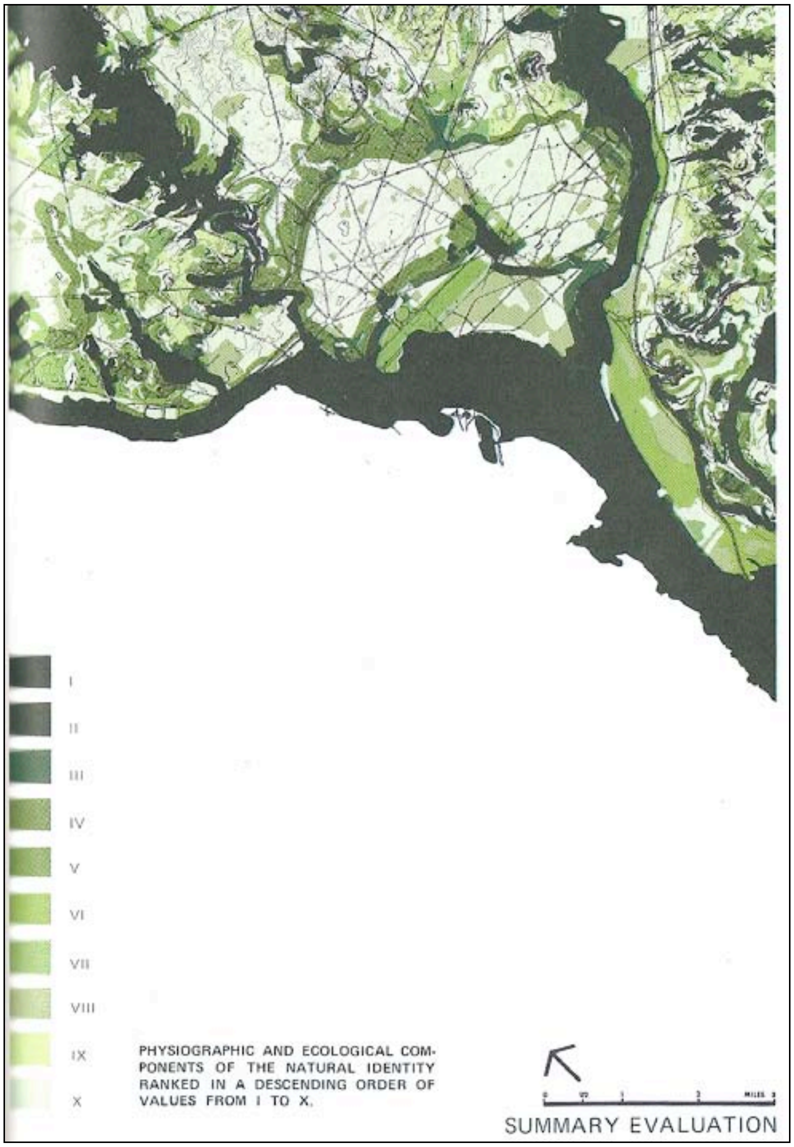
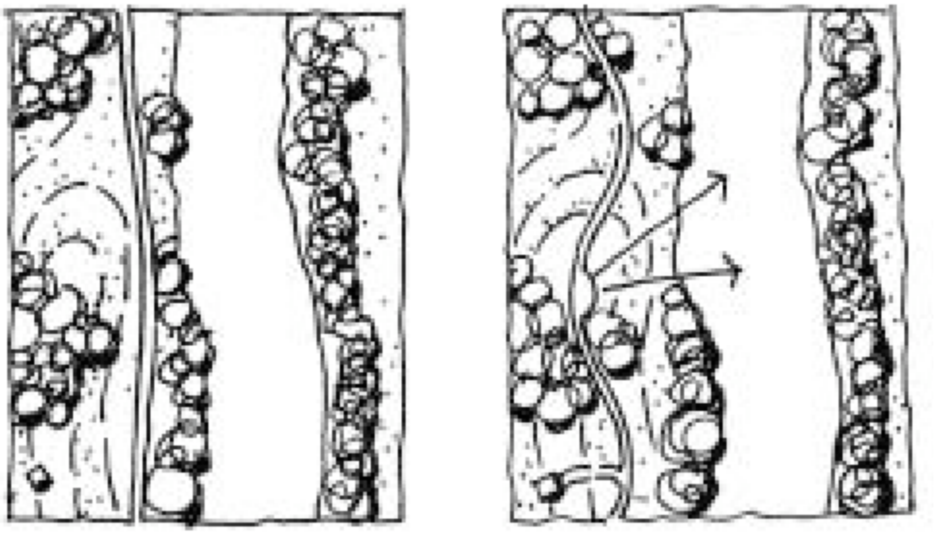


Figure 3. Hellmund and Smiths' (2006) illustration of two alternative trails along a river greenway. In (a) the trail is straight and maintains a uniform distance from the stream edge. In contrast, in (b) the trail meanders along the stream edge and diverges away to a hill with a historic site, returns to the stream edge, and then diverges away to a forest (from the bottom to the top of the drawing).



(a) (b)

Figure 4. Richard Forman's four indispensable patterns for ecological landscape planning (in Ecology and Design 2002). The second pattern, continuous riparian corridors along streams is emphasized with a green color.

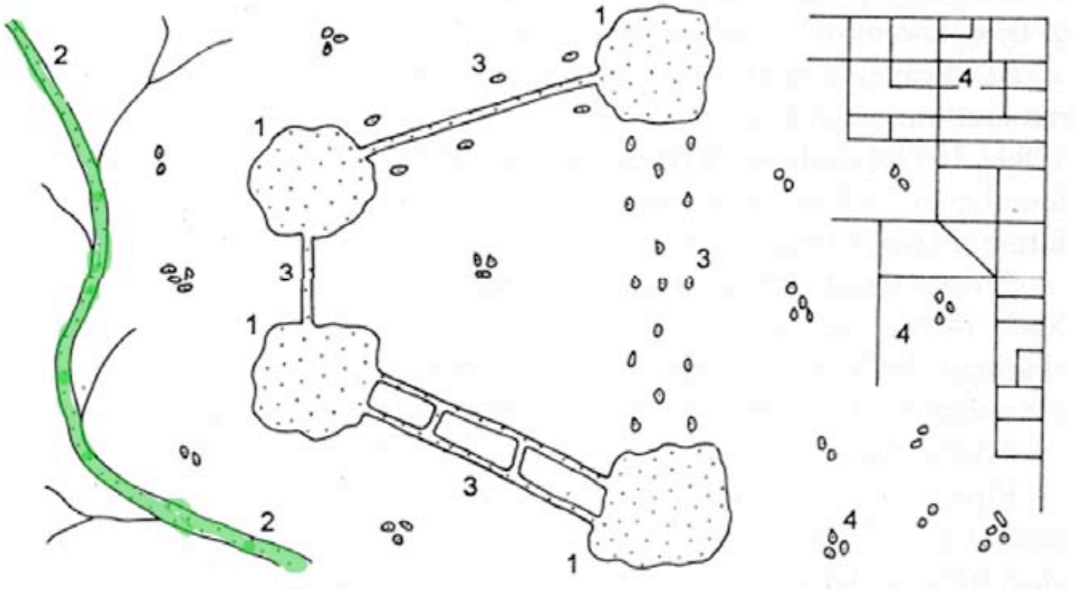
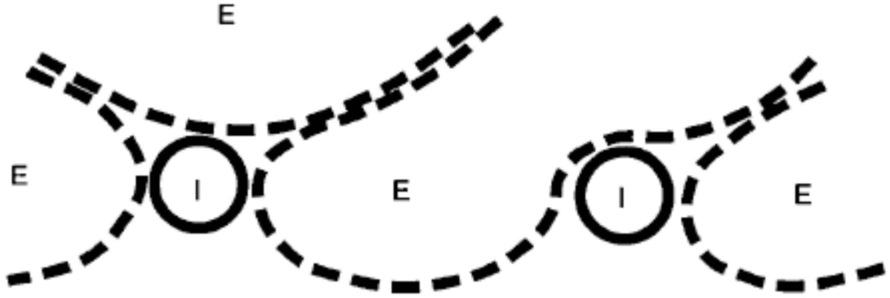


Figure 5. Manning's (1997) planning for extensive and intensive gradients of human use and natural areas with little human use represents a socio-ecological planning approach.



Extensive–intensive gradients. 'E' zone = diluted human content, increased natural potential. 'I' zone or focus = concentrated human content and pressure, the most artifice, the least natural potential. E–I gradients occur everywhere, on all sites, at all scales of landscape event.

Chapter 2

The ideal s-curve: Evaluating the influence of Hogarth's aesthetic theory on Capability Brown's 18th century river bends and 20th century river restoration meanders

Abstract

This study evaluates the similarity between William Hogarth's 18th century aesthetic theory on beauty and two sets of river designs: 18th century river bends by Capability Brown and 20th century channel realignments by river restoration practitioners. I first reviewed the design approach and construction methods used by Brown and the restoration practitioners. Then, I compared the form of Hogarth's line of beauty, an ideal s-curve, with the river curves using two indices of curvature, sinuosity and symmetry. I found that although the sinuosity of Brown's river bends matched the line of beauty (mean S=1.2), he created a variety of large water features by damming small streams and taking advantage of existing topography. In contrast, the river restoration projects created an idealized meander form with a predetermined sinuosity, greater than the line of beauty and Brown's river bends, by digging out new channel paths. Both the line of beauty and the river restoration meanders exhibited almost perfect symmetry, even though river meanders in nature are not symmetrical. Although this study is limited to two quantifiable variables, sinuosity and symmetry, it is the first to examine the form of an aesthetic theory in relation to classic and recent river channel design.

2.1 Introduction

Landscape scholars have inferred a connection between William Hogarth's 18th century theory on beauty and 18-21st century landscape design. They note the similarity in the form of Hogarth's line of beauty, illustrated in his book the *Analysis of Beauty* (1753) as an s-curve with two contrasting curves of equal depth moving in opposite direction, and landscape designs with sinuous curves and serpentine shapes. Gothein (1913) wrote that Capability Brown an 18th century English landscaper was the first advocate of the line of beauty. Stroud (1950) saw Capability Brown's serpentine landscapes as built representations of Hogarth's theories on beauty. The association between Hogarth's aesthetic theory and landscapes extends to 19th and 20th century designs in America: urban parks, national parks, suburbs, golf course, and corporate campuses (Mozingo 2011, Porteous 1996, McClelland 1993, Jellicoes 1975, Carr 1958). One example of a landscape that appears strikingly similar to Hogarth's line of beauty and Capability Brown's serpentine river bends are river restoration projects where a new channel path with s-curves replaces a formerly degraded river reach (Kondolf 2006). While the visual connection between Hogarth and river curves by Capability Brown and river restoration practitioners appears plausible, there has been no analysis of the similarity.

Hogarth's theory on beauty is distinctive because the line of beauty is precisely drawn and can be measured. Hogarth illustrated seven 's' shaped lines, with the curvature varying from almost straight to almost circular, and he defined the fourth line as the line of beauty (Hogarth 1753, Figure 6). Hogarth first drew the line in his self-portrait as an s-curve weaving across his artist's palette in place of a brush and paint (Figure 7). He defined beauty through the study of the human body, sculpture, paintings, and natural and man-made objects (Hogarth 1753, Figure 8). He believed the line of beauty was the most beautiful when expressing motion in a 3-dimensions form, which he called the line of grace. He identified six other principles contributing to beauty, "fitness, variety, uniformity, simplicity, intricacy, and quantity; -all which cooperate in the production of beauty, mutually correcting and restraining each other occasionally" (Hogarth 1753, 21). Although symmetry was not one of Hogarth's main principles of beauty, he believed it contributed to beauty by conveying fitness, which he defined as, "the bulks and proportions of objects" (Hogarth 1753, 23). As an example, he described a twisted column as potentially beautiful in itself, but if not suited to the purpose, i.e. supporting a weight, it will appear unfit. Variety adds to beauty as seen in the profile of a face as opposed to the front view, and simplicity adds to variety by making something more understandable. Uniformity gives the idea of rest and motion, while intricacy amuses the mind through challenge, leading "the eye a wanton kind of chase" (Hogarth 1753, 25). Finally, quantity is a principle of beauty because the vastness of a large shape; a large oak tree, Windsor castle, whales, or elephants, is more pleasing to the eye because of its size (Hogarth 1753).

The line of beauty differentiates Hogarth's theory on beauty from other aesthetic theorists such as Edmund Burke. Burke wrote *A Philosophical Enquiry into the Origin of our Ideas of the Sublime and Beautiful* (1757) four years after Hogarth's *Analysis of Beauty*. He agreed that Hogarth's line of beauty was a characteristic of beauty, calling it "extremely just" as an element of gradual variation (Burke 1757). However, Burke disagreed with the idea that a specific line was more beautiful than another. He wrote, "there is no particular line which is always found in the most completely beautiful, and which is therefore beautiful in preference to all other lines.

At least I never could observe it" (1757, Part IV section 23). Although Burke's principles of beauty may have influenced 18th century English landscape designs (Hussey 1927), it is not possible to measure his theory, whereas it is possible to measure the form of Hogarth's theory.

Few studies delve into the details of Hogarth and Burke's principles of beauty as they appear in landscapes. An exception is Myers (2004) comparison of Hogarth and Burke's theories with the 20th century design of the Blue Ridge Parkway in North Carolina and Virginia (US). The Blue Ridge Parkway is considered one of the most beautiful roads in the US, and Myers (2004) explained how the principles of beauty trickled down through an educational lineage from 18th century England to influence the parkway designer. She concluded the parkway designer engaged Hogarth and Burke's principles of beauty, especially variety and motion, in creating the alignment and curvature of the road and adjacent landscape design. In this study, I built on Myers (2004) and Kondolf's (2006) work by exploring the relationship between Hogarth's theory and river designs by Capability Brown and river restoration practitioners using quantifiable variables of form: sinuosity and symmetry. The implications of this research are important for river restoration, because the practitioners rely on scientific study of natural rivers to determine meander dimensions and do not acknowledge aesthetic influences.

When restoring formerly meandering, artificially straightened channels, recreating meander bends makes sense as a restoration approach. The longer meandering channel has a lower gradient and a greater planform complexity, which can induce more complex bed geometry and habitats generally. Provided the current flow regimes and sediment loads still support a stable meandering channel pattern, this approach can be very successful, and has been implemented throughout Western Europe (Brookes 1987; Iversen et al. 1993). In the US, construction of meandering channels has been a common restoration approach, in some cases replacing irregular sinuous channels with idealized symmetrical meanders, and in other cases building symmetrical meanders on streams that were not naturally meandering (Smith and Prestergard 2005, Kondolf 2006). Many of these projects have failed, but even if they had not, fixing the river in a specific idealized path would likely limit ecological function. It is well established in scientific literature that dynamism in rivers, specifically actively migrating channels and instability, leads to ecological richness and diversity (Palmer et al. 2005, Wohl et al. 2005, Naiman et al. 1993). The persistent popularity in the US of a single-thread meandering channel in river restoration projects suggests there may be an unrecognized aesthetic preference for this channel form. This raises the question, how does the form of these contemporary restoration projects compare with the line of beauty specified by Hogarth in the 18th century?

2.2 Methods

I first reviewed the literature on the design approach and construction methods used by Capability Brown and river restoration practitioners. Despite the different methods of river construction, I compared the line of beauty to the form of the river curves (Figure 9). I measured the line of beauty as depicted in three of Hogarth's illustrations (Figure 8, Plate 1: 49, 50 and Plate IIa Variety, 1753) and measured the range from curve #1 to curve #7 (Figure 6). I found copies of twelve landscape plans by Capability Brown; however, some lacked a scale or the scale was illegible, so I limited the study to sites where the lake or river bend did not change through time and measurements could be made using recent satellite imagery (Google Earth). At ten sites, the form of the water features today matches Brown's plans (ca. 1750–1782): Ashburnham Place, Blenheim Palace (two sites: lake and the New River downriver of the lake and cascade), Bowood, Coombe Abbey, Heveningham Hall, Packington Hall, Petworth House, Rothley, and Trentham. At Heveningham Estate, the lake was constructed in the 1990s in an effort to realize Capability Brown's original plan for the first time. I selected four river restoration projects studied by Kondolf (2006) where the restoration practitioner constructed a new channel and for which plans were available: Uvas Creek, Deep Run, and two reaches of Greenhorn Creek, Farnworth and Nickel-Miller. All of the restoration sites are in California except for Deep Creek, which is in Maryland, and they were built from 1991–1995. The stated purpose of the four river restoration projects was to improve the stability of the channel, reduce erosion, reconnect the floodplain and/or improve the trout habitat (ACOE 1991, MSHA 1991).

2.3 Measuring Form

I recorded the mean number of meanders, length of the constructed reach, and channel width for both the Brownian water features and the river restoration projects. I measured length along the centerlines of both. I measured widths of Brown's water features by making measurements perpendicular to the mid-line every 150 m. For the restoration projects I used the bankfull width as the channel width. The restoration project plans had tables summarizing the ideal meander dimensions, such as the meander length, radius of curvature, and sinuosity. I recorded these dimensions and compared them to our measurements of the meanders in the restoration plan.

Hogarth's illustration of the line of beauty does not contain a scale so the length and width cannot be measured; however, I quantified the shape using two dimensionless parameters, which do not change with scale: sinuosity and symmetry. I compared the sinuosity and symmetry of the line of beauty to Capability Brown's river bends and river restoration meanders. Sinuosity (S) is an index of the amount of curvature.

$$S = \text{length along curve/straight line length}$$

A straight line with no curvature has a sinuosity value of one. I measured the distances between the two inflection points of a single wavelength (s-curve) and calculated a mean sinuosity for sites with multiple wavelengths. Scientists use this method to study river channel patterns, measuring the length along the stream divided by the downvalley length (Knighton 1998). A sinuosity, S=1.5, was found to be the median value of meandering rivers, differentiating them from straight or braided rivers with multiple channels (Leopold et al. 1964).

To characterize the symmetry (z) I used Carson and Lapointe's (1983) river asymmetry index:

$$z = 100*u/(u+d)$$

where d is the length of the transverse that is convex and u is the length of the concave part of the transverse from the minimum to the maximum apex (Figure 10). A single traverse contains one inflection point. Asymmetry exists when $z<45$ and $z>45$. I followed their method and excluded all traverses with an inflection angle <30°, the angle between the downvalley direction and the centerline of the river curve (Figure 10). Carson and Lapointe (1983) analyzed the median value of convex down-valley traverses in rivers, or the asymmetry. They found median values of z=68, 57, and 56 on the Rogue, Beaton, and Pembina Rivers, respectively (Carson and Lapointe 1983). Applying their asymmetry index to river meanders studied by Brice (1974), Carson and Lapointe (1983) found that 45% of the 202 traverses reanalyzed were highly asymmetric (z<30 or z>65) and 82% were convex downvalley. Symmetry can occur even if the u and d values differ (Figure 10, C and D transverses); however, I wanted to know the portion of perfectly symmetrical curves (z=50) with equal u and d values. Carson and Lapointe (1983) noted the method was challenging because defining the direction of the valley axis, what they called the local meander belt axis, and the point of inflection is somewhat subjective. I compared the sinuosity of the two sets of river curves with an Anova. Due to the small sample size for the line of beauty (n=3) I compared it qualitatively but not statistically with the two sets of river curves.

2.4 Results

2.4.1 Design Approach and Construction Method

Capability Brown's landscapes usually included a large serpentine lake or widened river meander made by damming a small river to create an aesthetically pleasing view and landscape experience. The lake at Blenheim is considered iconic of 18th century English landscapes with its sinuous curves and grandness (Stroud 1950, Hyams 1971, Turner 1985, and Hinde 1986). Unlike Brown's contemporaries, he did not leave behind a body of written work, so researchers have had to piece together his work based on his account books, a few surviving plans, and notes from guests and travelers. Typically, small rivers or springs fed Brown's dammed water features and they collected water from the adjoining land area. Brown regraded the topography to shape the form and edges of the lake. In a contract for the lake construction at Trentham, Brown wrote the lake should be dug to four feet (1.2 m) deep in places, "wherever it is not so naturally" and to fill in "such parts of the [River] Trent as does not fall within the Bed of the intended Water" (Brown 1759). Brown's design for the lake and new river at Blenheim is iconic of the 18th century English landscape with its sinuous curves and grand expanse (Stroud 1950, Hyams 1971, Turner 1985, and Hinde 1986)(Figure 11). At Blenheim, Brown transformed the River Glyme so that it was as wide as the Thames River in London and redesigned the New River below the cascade at the lake terminus with a half-mile long embankment (Figure 12, Stroud 1950, Hyams 1971, Turner 1985). Brown exclaimed, "Thames, Thames, you will never forgive me," upon completing the transformation of the River Glyme into the Queen's Pool and Broadwater at Blenheim (Hussey 1927, Figure 12).

While Capability Brown made dams to form large serpentine lakes and widened streams through new courses, in the four stream restoration projects the meander alignments were based on application of the Rosgen classification system and were converted to "C3" and "C4" meandering type channels, considered as "desirable from a biological and aesthetic viewpoint" (Rosgen 1997, Rosgen 1994). Prior to their reconstruction, the streams were classified by the restoration practitioners as "G" and "F" type, which were considered to have incised below their floodplains (ACOE permit 1991, Plumas 1991, 404 Permit 1992, Zembsch 1993). The Rosgen method classifies river types based on morphological similarity and uses a stable reach as a reference for the restoration. "C" type channels are defined as non-entrenched single-thread alluvial channels with well-developed floodplains, broad valleys, and sinuosities of around 1.8 (Rosgen 1994). The morphological similarity is determined by the entrenchment ratio, width-to-depth ratio at bankfull discharge, sinuosity, slope, and substrate size (Rosgen 1994). The entrenchment is the ratio of the river width at a bankfull discharge to the width of the valley floor (Rosgen 1994).

To restore the entrenched streams designated as “F” or “G” types stream channels at Uvas, Deep Run, and Greenhorn, the restoration practitioners constructed “C” channels with new channel dimensions, patterns, and profiles. This restoration approach is of questionable suitability in geomorphic settings such as the Coast Range of California, where the flow regime is highly variable and the streams transport high sediment loads, producing a wide, active, braided channels (Kondolf 2006). These are episodic channels in which large floods reform the channel by scouring vegetation from the bed and converting single thread channels into multiple thread channels (Stein et al. 2011, Hecht 1994). The Rosgen restoration method involves choosing a stable reach from which channel dimensions are drawn for the restored reach. Restored meander bends are constructed by digging out a new channel path, installing rock weirs, and armoring the outside of bends with tree roots or large rocks to prevent erosion and train the river along its new course (Figure 13).

Restoration practitioners would describe their designs as geomorphologically based because they employ ratios for meander wavelength as functions of channel width. These relations were popularized by Leopold and Wolman (1957), who found the radius of curvature was 2.42 times the width and meander length was roughly 11 times channel width. Langbein and Leopold (1966) described the course of a river meander as following a sine-generated curve and theorized that meanders take a regular form with identical bends when conditions are stable or homogenous. However, they recognized that deviations resulted from variations in the composition of valley alluvium, and the presence of features such as snags and bedrock outcrops. It is instructive to examine figures used to illustrate meander dimensions in textbooks and manuals, which typically show a single regular s-curve (Figure 14). However, most river meanders are not symmetrical. Carson and Lapointe (1983) found that asymmetry is inherent in river meanders and compound forms are not uncommon in nature, while St∅lum (1996) concluded that rivers oscillate between high sinuosity (S~3.5) reaches characterized as chaotic and asymmetric, and low sinuosity (S~2.7) reaches characterized as ordered and symmetric.

Despite the different design and construction methods used by Capability Brown and 20th century river restoration practitioners they may have both been aiming for an ideal form. In Brown’s case, the ideal form may have been Hogarth’s line of beauty or the Thames River as seen from Richmond Terrace in London. In the case of the 20th century projects, the practitioners used a reference stream type as the basis for the design, but may have also been influenced by the theorized ideal meander depicted as a single channel with regular bends or perhaps by unacknowledged aesthetic preferences for curves like Hogarth’s line of beauty.

2.4.2 Form Comparison

Capability Brown’s river bends usually contained one s-curve; however, the form of the lakes varied from straight (e.g., Packington and Kirtlington Estates) to double serpentine lakes split by land (Ashburnham, Rothley), to lakes that curve around like a hook with only one half of an s-curve (Figure 9). The river restoration projects contained an average of three individual s-curves (Table 1). Brown's river bends were approximately 3 times longer and 8 times wider on average than the river restoration meanders. The mean sinuosity of Hogarth's line of beauty, curve #4, was 1.2; curve #1 the low-end of the range, considered too straight, had a sinuosity of S=1.0; the high-end curve #7, considered too wavy, was S=1.3. The mean sinuosity of Brown's river bends matched the line of beauty (S=1.2, standard deviation 0.1), while the sinuosity of the river restoration meanders was much higher (S=1.4 measurements from the design plan, standard deviation 0.11). The difference in sinuosity between Brown's river bends and the 20th century river restoration meanders was significant ($F_{1,23}$=11.7, P=0.002). The line of beauty and the river restoration meanders were both highly symmetrical and had the same median value, z=52. Symmetry could be calculated for only three of Brown's river bends, those with inflection angles >30°: the Queen's Pool at Blenheim (lake upstream of the bridge), the New River at Blenheim, and Petworth, and the median value of these two sites was z=69. Thus, to the extent that symmetry can be measured, Brown's water features were not symmetrical.

The mean sinuosity measured from the river restoration plans was less than the ideal dimensions listed in the summary tables in design documents for these projects. The largest difference was at the Greenhorn Creek sites: Nickel-Miller differed in sinuosity by 0.65 (ideal S=2.0, measured S=1.35) and Farnworth by 0.43 (ideal S=1.8, measured S=1.37). In Uvas Creek (ideal S=1.5, measured S=1.32) and Deep Run (ideal S=1.4, measured S=1.43) the difference in the sinuosity was less than 0.05. There were notes in the Greenhorn Creek restoration documents regarding difficulty in building the specified sinuosity due to river confinement. In the Nickel-Miller and Farnworth sites the practitioners specified that if the high sinuosity cannot be achieved due to confinement than the design could be adjusted to a lower sinuosity (Plumas Corporation 1991).

2.5 Discussion

Brown was probably aware of Hogarth's line of beauty and the sinuosity of his river bends was closer to the line of beauty than were the 20th century river restoration projects. However, the variety in Brown's river bends indicates he was making practical decisions about the form during construction of the water feature. Additionally, the fact that Brown mostly took advantage of existing topography where possible limited his ability to make an idealized s-curve. Brown achieved an s-curve in some features, a c-shaped curve in others, and some of his lakes were almost straight. This was evident when I tried to measure the symmetry and found that almost all of Brown's lakes had small inflection angles representative of straight forms with low curvature. There were probably other considerations in the water feature beyond the form: the perspective from the house and from the ground beside the water, the location of pre-existing canals or fishponds, the size of the river bend relative to the scale of the entire landscape, and the creation of a variety of different water features.

The scale of Brown's river bends was large and if he was applying Hogarth's principles, he may have been drawing more on principles of quantity, fitness, or variety as opposed to the line of beauty. Brown 's ideal may have been the curve of the River Thames in the celebrated view from Richmond Terrace (Turner 1985; Moritz 1782). The River Thames is the second largest river in England, much larger than most rivers in the UK, which are small. Brown may have wanted the lakes to appear grand like the Thames, so they would embody fitness, Hogarth's most important principle of beauty, in that they fit with the large scale of the estate house and entire landscape design. Another reason for Brown's large-scale river bends may have been to employ Hogarth's principle of quantity, which he described as vastness and big features. Finally, Brown also created variety, another of Hogarth's principles of beauty, in different water features at Blenheim: an expansive sinuous lake, a cascade tumbling over rocks, and a widened river bend downriver. This study could be expanded in the future to include Hogarth's additional principles of beauty or expanded to other relevant aesthetic theorists such as those of Edmund Burke (1757).

The sinuosity of the river restoration meanders in the 20th century projects did not match Hogarth's line of beauty. The sinuosities were greater than even Hogarth's curve #7, which he considered to be too "bulgy" and not beautiful (Hogarth 1753). The restoration meanders were based on reference stream types and ideal meander geometry relations, and were highly symmetrical, unlike meander bends in most natural rivers. Even the illustrations in text and reference works portray meanders as single "s-curves" with regular bends, as opposed to irregular, asymmetric, or braided rivers with multiple channels (Leopold 1994, Langbein and Leopold 1966, Hasfurther 1985, Soar and Thorne 2001). However, regularity in meanders is rare in nature and does not persist over long reaches; rather asymmetry characterizes many stream meanders (Carson and Lapoint 1983, Stolum 1996). Scientific papers on meandering characteristics appear to have been based on selected meander bends that exhibited exceptional symmetry in comparison to the other rivers and even to other reaches of the same river (Leopold 2004).

2.6 Conclusion

Beauty is difficult to quantify and Hogarth's theory consisted of qualitative descriptions and one clear illustration of his principles of beauty. I isolated the line of beauty because it provided a measurable example of an aesthetic ideal, which I could compare to both Capability Brown's river bends and river restoration projects. I show that the form of Brown's river bends matched the line of beauty in sinuosity but was highly variable, while 20th century river restoration meanders were more sinuous. Brown river bends were all large-scale and may have reflected his desire to mimic a bend of the Thames River or to employ some of Hogarth's additional principles of beauty. Both the line of beauty and river restoration meanders had symmetrical curves. Symmetry in river restoration is a theorized ideal condition that is counter to research showing that dynamism in rivers, specifically actively migrating channels, leads to ecological richness (Palmer 2005, Wohl 2005, Naiman 1993). This study does not answer the question should river meanders be symmetrical, it answers the question are river restoration meanders exhibiting an aesthetic ideal? I found the high level of symmetry in the 20th century river restoration meanders provides evidence for an aesthetic influence.

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Table 1. Summary of data for the line of beauty and two river designs.

Sample	**Sample size n**	**# Meanders analyzed**	**Mean *S***	**# Traverses analyzed**	**Median *z***	**Mean Design Length (m)**	**Mean Design Width (m)**
Line of Beauty	3	3	1.2	3	52	-	-
Capability Brown Designs	10	13	1.2	11	49	1,290	95
River Restoration Designs	4	12	1.4 *1.7	27	52	366	11

* The mean ideal sinuosity specified in the design tables for the river restoration projects.

Figure 6. William Hogarth's illustration of the line of beauty, curve #4 (1753).

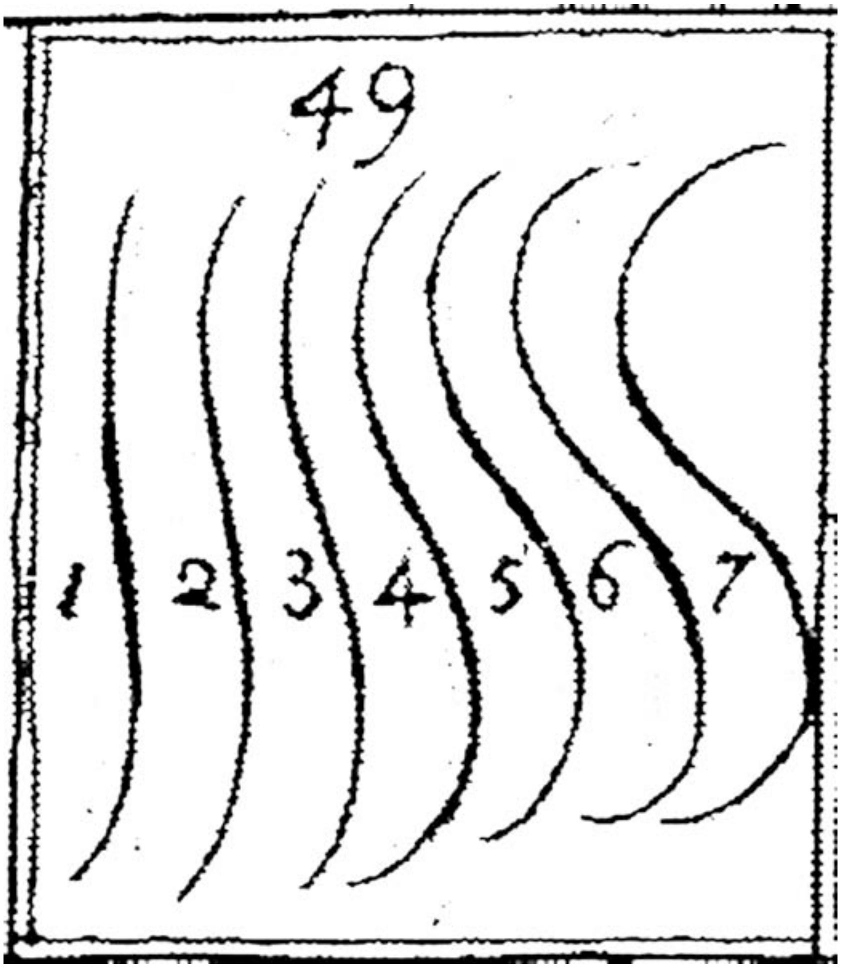


Figure 7. William Hogarth's self-portrait with his dog and artist's palette showing the line of beauty and grace taking the place of paint and brush. The s-shaped curve formed the basis of his theory on beauty. (AKG Images, Location: Tate Gallery, London, UK)

Figure 8. In Hogarth's *Analysis of Beauty* (1753) he identified a specific line that represented the most beautiful curve, #4 in Plate 49 and 50 and the corset at the bottom of the illustration. In plate 26 Hogarth made the line of beauty three-dimensional and defined it as the 'Line of Grace'.

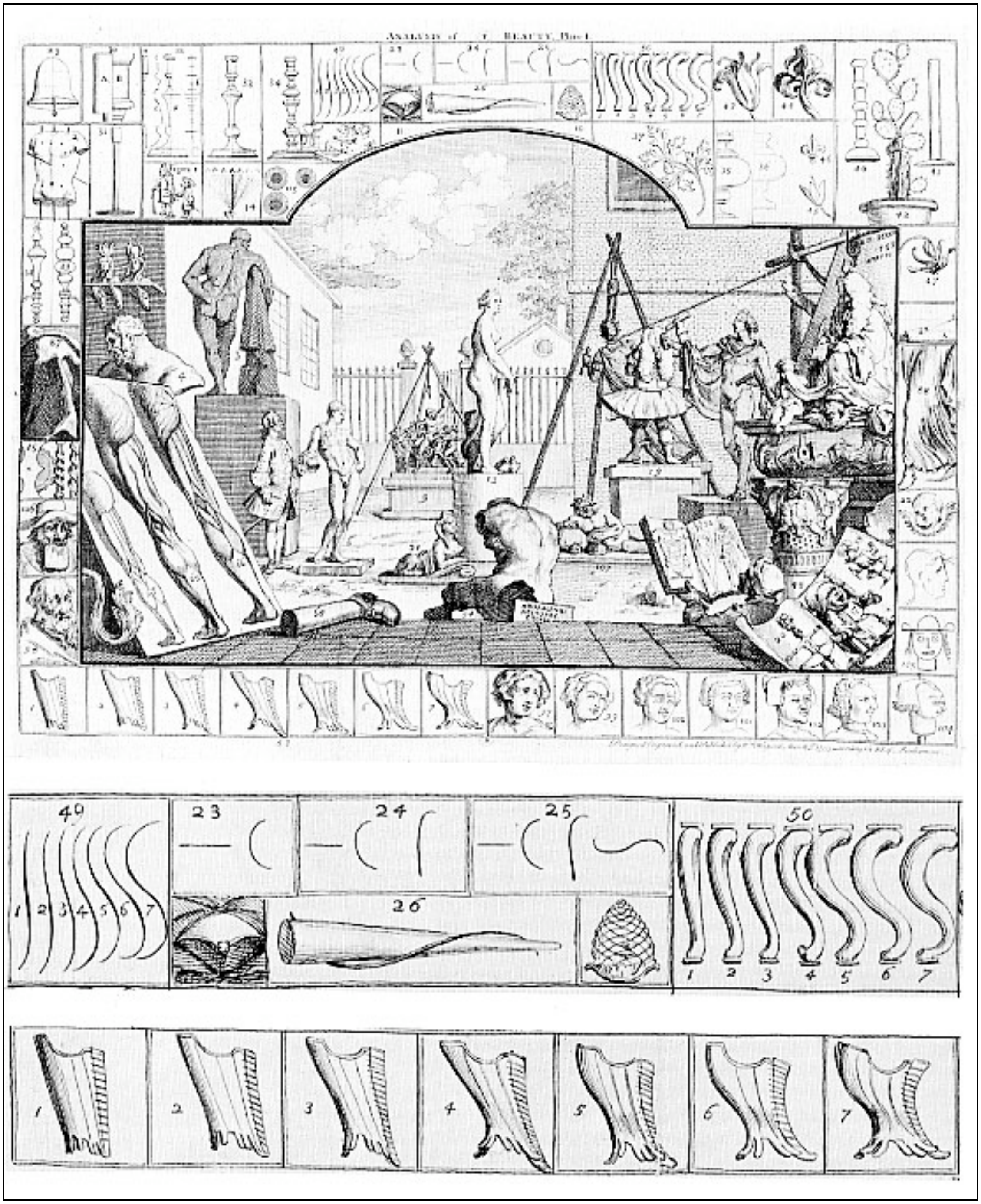


Figure 9. The three sets of s-curves compared based on sinuosity and symmetry.

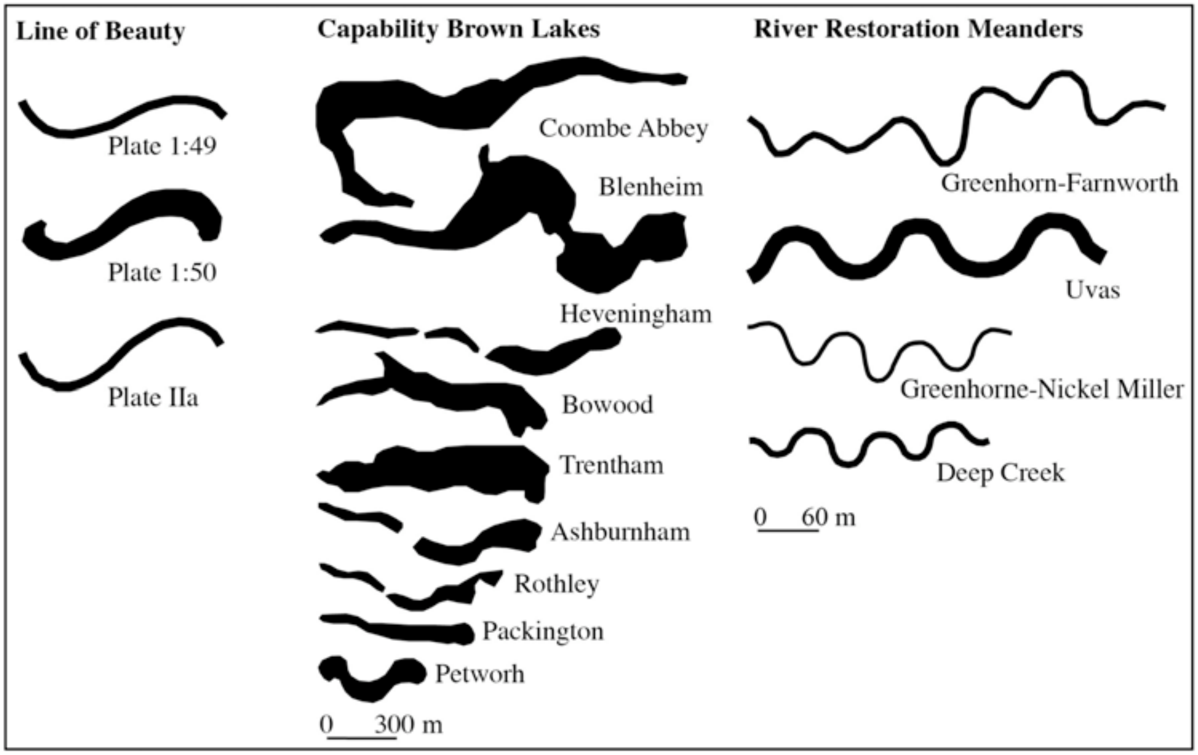


Figure 10. Diagram of symmetry measurement from Carson and Lapointe 1983. Transverse A is asymmetric while B is symmetric.

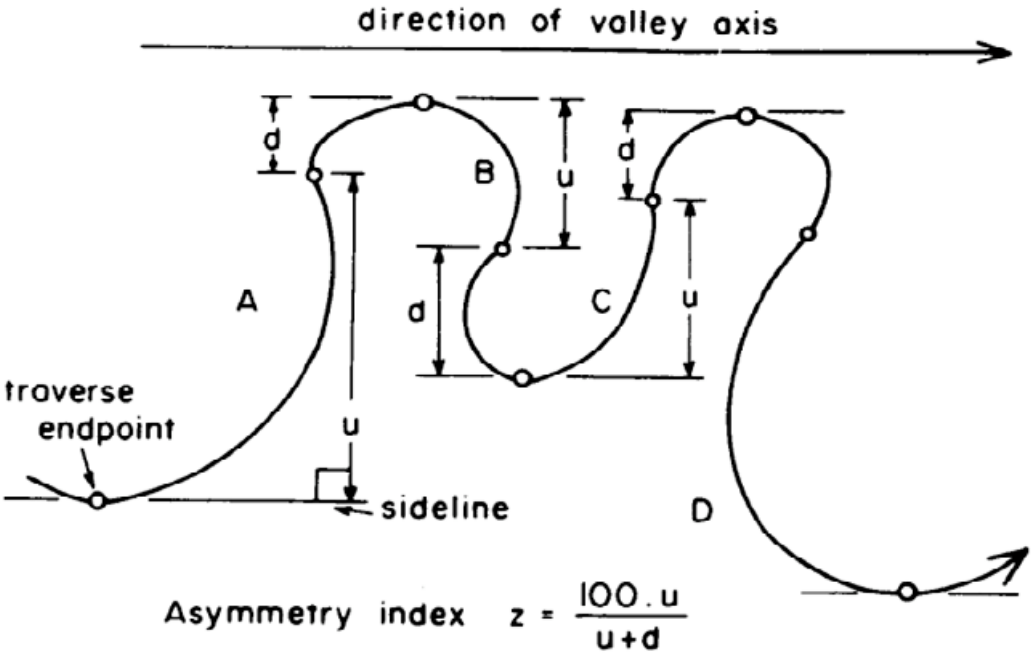


Figure 11. Looking north from Vanburgh's bridge onto the Queen's Pool at Blenheim Palace. Brown's man-made lake takes on the physical form of a meander bend in a large stream. (Photo by author, July 2009).

Figure 12. Capability Brown constructed the Queen's Pool and Broad Water by damming the Glyme River. He modified the dam to be a cascade and altered the channel downstream into the New River.

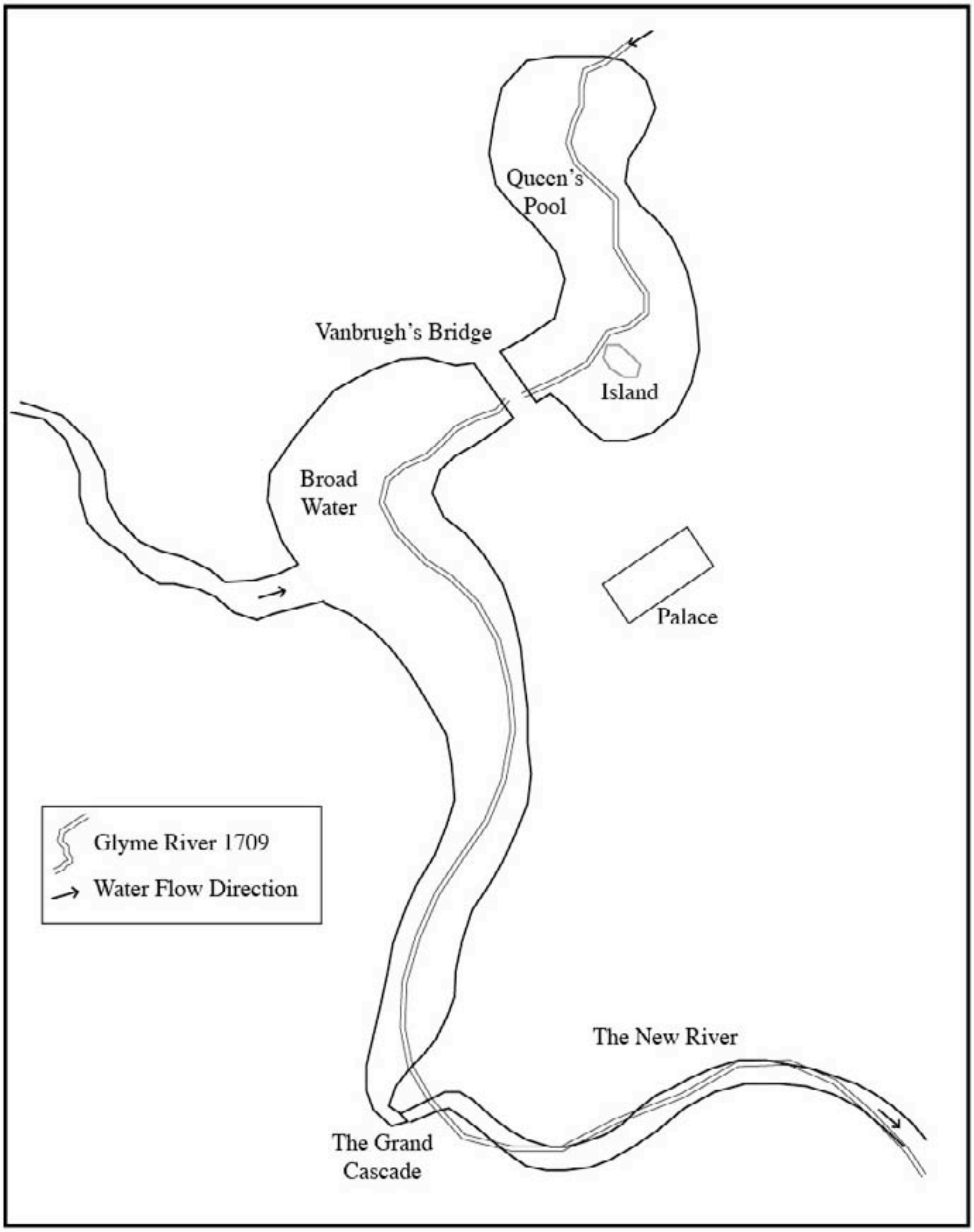
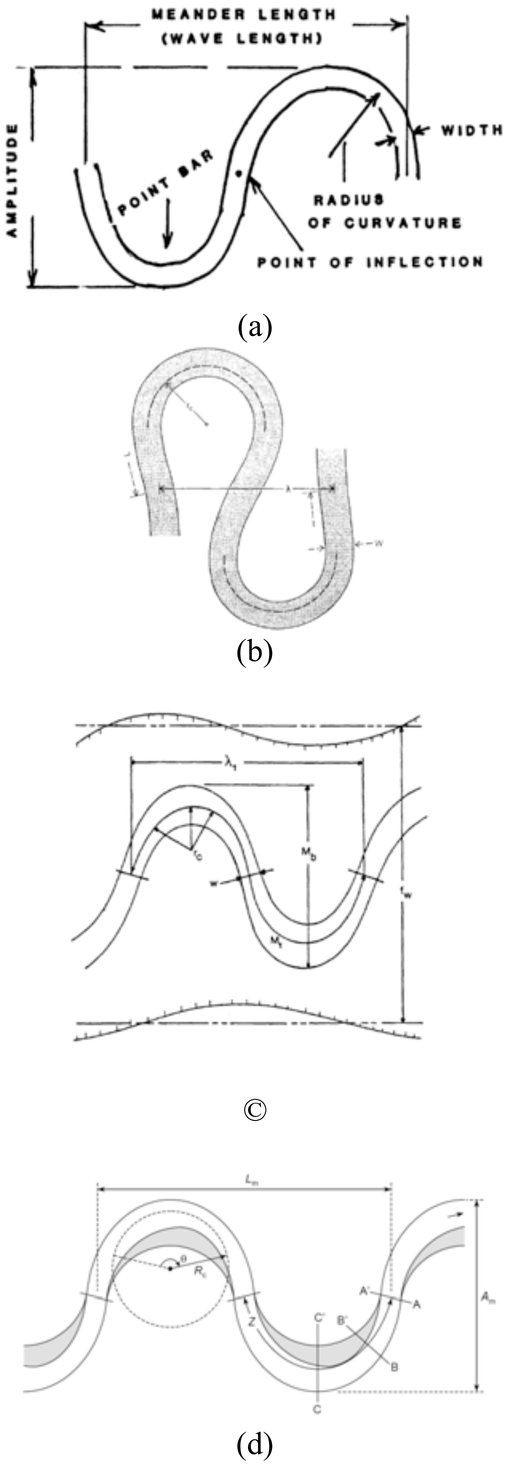


Figure 13. Uvas Creek restoration with armoring on the outside of the bends and rock weirs spanning the channel in January 1996, two months after construction (City of Gilroy, from Kondolf 2006).

Figure 14. Illustrations of regular meander dimensions depicted as a single s-curve in (a) Leopold (1994), (b) Langbein and Leopold (1966), (c) Hasfurther's (1985) *The use of meander parameters in restoring hydrologic balance to reclaimed stream beds*, and (d) the US Army Corps of Engineers (Soar and Thorne 2001) restoration design guideline for meander planform.



(a)

(b)

©

(d)

Chapter 3

Designing with Nature? The persistence of Capability Brown's 18th century water features

Abstract

McHarg (1969) and others portray 18th century English landscapes as examples of designing with nature and self-perpetuating. Through analysis of original plans, historical topographic maps, and current satellite imagery, I documented the persistence of Capability Brown's water features. I assessed the underlying geology of each site to determine if Brown accounted for local sediment yield rates in his designs. I expected that sites in the glaciated northwest, where river systems are more active, would fill with sediment more than sites in the southeast. I interviewed estate managers to determine the maintenance requirements of each water feature. Out of a sample of 53 water features, I found 37 (70%) exist today as Brown planned them more than two centuries ago, a better survival rate than enjoyed by the surrounding landscapes (51% as documented by Stroud in 1950). However, the persistence of the water features is largely attributable to periodic maintenance: out of 27 estates responding to our inquiries, 18 (67%) reported dredging or vegetation removal to maintain the water features. I did not find evidence that Brown accounted for local sediment yield rates in his designs, nor did I find different patterns in sedimentation or dredging histories of the water features. Although Brown's water features may look natural, they survive because of significant human intervention. Given contemporary interests in managing for habitat and restoration, the current management regimes require consideration of both historic preservation of iconic elements of the English landscape and ecological conservation values.

3.1 Introduction

In *Design with Nature* (1969) Ian McHarg describes 18th century English landscape designs as a "precursory ecology" (p. 73). To McHarg these landscapes represent a revolutionary transformation in humans view and relationship with nature towards a unity of the two.[1] As he wrote, "Never has any society accomplished such a beneficient transformation of an entire landscape. It is the greatest creation of perception and art of the western world and it is a lesson still largely unlearned" (McHarg 1969:73). The landscapes of 18th century offer hope that designers could understand nature's laws and forms and use them to accelerate the restoration of degraded landscapes, as a doctor would treat a sick patient. Jellicoe describes the transformation similarly, "Nature was no longer subservient to man, but a friendly and equal partner… A new conception of space and of man's relation to environment had appeared" (Jellicoe and Jellicoe 1987:233). McHarg contrasts 18th century English landscapes with 16th and 17th century gardens, where human's control over nature appeared in the imposition of a linear geometry and a selected nature, identifying the long meadow as the only artifice of 18th century English landscapes, the rest "deriving in the first place from that observed in nature" (McHarg 1969, 73).

Several scholars have critiqued the interpretation of 18th century English landscapes as ecological and highlighted their extensive underlying engineering and construction. Rogers (2001) equates Capability Brown's 18th century English landscape design to André Le Nôtre's 17th century French Baroque garden design. Both required massive earth movement and topographic revisions to achieve an idealized landscape aesthetic. Hunt (2000) refutes as simplistic and naïve the characterization of English landscapes as ecological (and therefore good), versus geometric designs of previous eras as unecological (and therefore bad). In a review of Ian McHarg's science, Herrington wrote the "zeal for the superiority of English landscape gardens glosses over both the human and site subjugation resulting from their creation" (Herrington 2010, 9). She observes that McHarg viewed the English landscape and thought it looked natural and so concluded it must exemplify design with nature (Herrington 2010). As others document, well-cared for and well-maintained landscapes may appear natural, even when there is little ecological value (Gobster et al. 2007).

Whether seen as natural or highly constructed, 18th century English landscapes have endured through time (Williamson 1995). McHarg (1969) argues that the ecological design of these landscapes explains their persistence. "It is a testament to the prescience of Kent, Brown, Repton and their followers that, lacking a science of ecology, they used native plant materials to create communities that so well reflected natural processes that their creations have endured and are self-perpetuating" (McHarg 1969, 72). Jellicoe similarly states that Capability Brown and Humphrey Repton's landscape designs were, "simple to make and maintain," and they explained the landscapes survived because of their nostalgic appeal and individuality (Jellicoe and Jellicoe 1987, p. 233).

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[1] McHarg (1967) defined nature as a process of physical and biological evolution, which fits within Williams (1976) end of the 18th century definition of nature: not man-made unless it was made a long enough time in the past that it is now seen as natural and associated with goodness and innocence. Williams (1976, p. 223) cites this as one of the most "powerful uses of nature" and one that retained currency since the 18th century.

In this study, I focused on Brown's water features (as distinct from the surrounding landscapes), documenting their persistence through time and assessing the water features as ecological design. I hypothesized that underlying geology and the fluvial context might explain differences in persistence, because some landscapes would have lower sediment yields and thus slower rates of lake siltation. In 1950, Stroud catalogued 211 landscape designs by Capability Brown into categories based on their condition, and I used this inventory as a basis for our current assessment of the status of the water features (Stroud 1950). Based on Stroud and our inventory, Brown's water features comprised of lakes and widened river bends have been even more persistent than the surrounding garden landscapes. Given that these lakes could have been expected to fill with sediment and vegetation over time, what explains the remarkable persistence of these features over two and a half centuries?

3.2 Capability Brown's water features

Serpentine lakes and river meanders gave signature beauty and structured drainage in Capability Brown's landscapes. The lake at Blenheim is considered iconic of the 18th century English landscape garden with its sinuous curves and grand expanse (Stroud 1950, Hyams 1971, Turner 1985, and Hinde 1987). Brown used a variety of techniques to construct the water features depending on the conditions at the site. His most common technique was to build an earthen embankment dam, dig out sections, and shape the edges of the lake to create an ideal form. Some dams were large, up to 210 meters long (Table 2).

In some sites Brown reshaped extensive topography and diverted rivers to create the shape of the water feature. Brown specified that the lake at Trentham be dug to four feet (1.2 m) deep in places, "wherever it is not so naturally" and to fill in "such parts of the [River] Trent as does not fall within the Bed of the intended Water" (Figure 15, Brown 1759). Brown's estimate for the lake at Corsham Court included "leveling round it," indicating shaping of the lake edges (Stroud 1950, 87). Brown widened, deepened, and rechannelized the New River section of the River Glyme at Blenheim with a half-mile long embankment, and widened and realigned the River Derwent at Chatsworth so that an entire meander bend was removed (Skempton 2002). In the widened river bend at Audley Estate, Brown built sluice gates at the northern end of the lake so that water could be let out for regular maintenance.

Several sites contained a pre-existing water body, typically a canal or fishpond, which Brown expanded and reshaped into long lakes. For example, Brown converted two former ponds at Burton Constable into a large lake separated by a bridge that also functioned as a dam between the two lakes. Brown connected the water flow between the two lakes at Ashburnham with a stone tunnel (0.6x0.8 m) that started in the middle of an island in the upstream lake and flowed into the downstream lake, perhaps because the estate owner preferred calm water to a cascade (Hinde 1987). Typically, small streams or springs fed Brown's dammed water features and they also collected water from the adjoining land area. At Croome Court, Brown created a drainage system to drain the surrounding landscape and fill the approximately 2,000 meter serpentine lake using nearby springs (Roberts 2001). He also used land drains at Thorndon and Wimbledon lakes (Land Use Consultant 2004, Sim Comfort, Wimbeldon Park Heritage Group, e-mail message to author, April 26, 2011).

At Heveningham Estate in 1781, Brown devised two designs, one for the gardens around the estate to the south, which was implemented at the time, and another to the north, which involved damming the River Blythe and creating a chain of three lakes nearly two miles long. This latter plan was not implemented at the time, possibly because of Brown's death in 1783. In the 1990s, landscape architect Kim Wilkie realized Capability Brown's plan, following the shape, size, and construction details in Brown's design (Figure 16). The River Blythe is ghosted onto Brown's plan to the south of the lake and Brown designed a sluice had been constructed to allow occasional diversion from the river to the original water bodies, two stew ponds leftover from the seventeenth-century house. Groundwater is sufficient to fill the lake, permitting the lake to be separate from the river (Kim Wilkie, Landscape Architect, e-mail message to author, July 2, 2010). A similar project is ongoing at Kirkhale Estate, Brown's birthplace and where he laid out his first design before the age of 23, but which was never constructed (Low 2009). In the 1970s, the estate owner found Brown's plans in his grandfather's desk drawer and decided to make them a reality as a living memorial to Brown (Low 2009).

3.3 Methods

I studied fifty-three water features by Capability Brown, identified from a literature search, Stroud's personal research notes (specifically her fourth edition notes held at the Soane Museum, London), and archival materials at the National Archives in London (Stroud 1950, Turner 1985). I limited the study to sites where Brown's lake and river meanders were distinguishable from the influence of subsequent designers. I included a water feature only if an estate manager, estate owner, or primary literature confirmed it was by Brown, and the feature had to be visible on a map scale (e.g., a single cascade would not be visible). (See Appendix for 63 sites not included.)

I traced the persistence of the water features through time using Brown's plans, historical and recent maps, and satellite imagery. For sites with available plans (n=9), I compared the water features to the earliest historical Ordinance Survey Maps (OS) from 1840-1892, which effectively documented how the water bodies appeared halfway between their late 18th century construction and today, roughly a century post-construction. Next, I compared the historical OS Maps to current OS maps and recent satellite images (Google Earth) to understand changes over the last approximately 150 years. I compared the first half of the features' existence (OS maps) to the second half (OS maps and satellite images) and looked for evidence of sedimentation and loss of open water in the lake or river bend outline. I assigned a value to the visual assessment to indicate the change through time, similar to the landscape status categories determined by Stroud: in existence, partly in existence, and lost, with the addition of a category for lakes restored post 1950. I compared the persistence of the water features to the persistence of the surrounding landscape garden.

I researched the geology underlying each of the water features to determine if Brown accounted for local sediment yields in his water feature designs. Brown's response to the local geology might be to keep the stream separate from the lake to reduce sediment input in places with high sediment yield. From the British Geologic Survey of England (1:625,000 scale) I recorded the lithology underlying each lake (DiGMapGB725). While England has globally low rates of erosion and sediment yield, there are differences between the more mountainous and glaciated Northwest and the Southeast, with its chalk and clay streams. I hypothesized that water features constructed in the more mountainous, glaciated northwest of England, with more active river systems, might have filled with sediment more than those in the southeast (Gregory 1997). I noted whether the site had been glaciated in the last glacial advance, as a potential factors affecting sediment yield from the catchment. I contacted estate managers and asked about dredging and vegetation removal required to maintain each water feature, as another source of information on sediment yield. I describe the maintenance requirements at four estates where detailed information was provided by estate managers, and which illustrate the challenges of managing ornamental lakes. Finally, I reviewed the literature relevant to management of Brown's water features for ecological value.

3.4 Results and discussion

3.4.1 Persistence through time

Surprisingly, 37 out of 53 water features (70%) exist today as Brown planned them more than two centuries ago (Table 3 and Figure 17). At Blenheim there was little change in the form of the lake through time (Figure 18). Twelve (23%) were partly in existence as Brown planned them (Figure 19). Only three have been lost to sedimentation and vegetation establishment: Euston Hall, Stratfield Saye, and Kimberley (Figure 20). At Euston the historical map shows a southern lake called the *Broad Water*, but contemporary satellite images show the separation of the once long, continuous lake into two smaller remnants of open water due to sedimentation and vegetation growth. Similarly, the *Broad Water* at Stratfield Saye now contains two long vegetated islands that decrease the open water effect. At Kimberley Lake the southern end of the lake also filled in with sediment and vegetation and the island is no longer present. The persistence did not relate to the length of the water feature: Kimberley was on of the shortest at 269 meters and Euston Hall one of the largest at 1,199 meters.

In contrast to the persistence of these water features, Stroud's (1950) assessment of the landscape status of the same sites (n=49) found that only 25 (51%) were still in existence, 7 (14%) were partly in existence, and 17 (35%) were obliterated (Table 3). Four sites are not included in this analysis because Stroud did not assign a value to the landscape persistence since she was not sure the water feature was Brown's (1950). At the 17 sites where Stroud ranked the Brown landscape as obliterated in 1950, 11 (65%) of the water features exist today as Brown planned them, 5 (29%) are partly in existence, and only one was lost (Euston Hall). Brown's water features remain even in the face of significant land use change. At Thorndon and Wimbledon Park surrounding gardens became a golf course and a variety of recreational landscapes around the lakes (Figure 21). Brown's lakes and river bends persisted even as other features of his landscape design were lost.

3.4.2 Local geology and sedimentation

I reviewed twelve copies of Brown's landscape plans and one original plan at Brockelsby Estate. On his plans, Brown noted the former channel alignment with a dotted line on his design plans, as seen on his plan for Horsham Estate where the difference between the narrow width of the former meandering stream channel and the wide width of the planned ornamental lake are clearly delineated (Figure 22). The constructed water feature did not always match Brown's plan, however, demonstrating that he had to adapt his plan to the conditions on the ground. At four sites the as built design matched Brown's plan almost exactly (Ashburnham, Blenheim, Bowood, and Trentham). In nine sites, the built form of the water feature was slightly different from Brown's plan. For example, at Castle Ashby, Brown had planned a continuous lake, but two lakes were constructed instead.

In addition to significantly altering existing water features during construction, Brown did not design the lakes based on an understanding of the local sediment yield. With a very few exceptions where the stream runs parallel to the lake, most of the lakes contain the stream that supplies the water thereby ensuring a continuous supply of sediment to the constructed water feature. Even at Trentham Estate where the stream runs parallel to the lake and thereby could be expected to reduce sediment input, the island in the lake shifted downstream and divided into three smaller islands, and a second unplanned island established at the head of the lake.

I did not find that local geology altered or affected the design of the lakes. The sites in the glaciated northwest did not experience greater sedimentation rates or require more dredging than sites in the southeast. There was also no relation between the local geology and vulnerability of water features to sedimentation. Euston Hall and Kimberley Hall, two water features that were entirely lost to sedimentation, were both located in the southeast and underlain by chalk (White Chalk Subgroup, British Geologic Survey of England). In chalk catchments, streamflow is primarily groundwater fed, and suspended sediment concentrations are typically an order of magnitude lower than other rivers (Heywood and Walling 2003). The only other water feature lost to sedimentation and vegetation growth, the lake at Stratfield Saye, was located in the south and underlain by clay, silt, sand, and gravel (Thames Group formerly called London Clay, British Geologic Survey of England). At Stratfield Saye the River Loddon flows northwest through a clay landscape with alluvial deposits close to the stream.

3.4.3 Water feature maintenance

The reply rate from estates regarding water feature maintenance was 30 out of 58 (52%). Of these, 21 of 30 (70%) indicated the water feature is dredged (Table 3). At Sheffield Estate and Sherborne Castle, the upstream end of the lake is used as a natural sediment trap that is regularly cleared out. At Sherborne the lake is dredged every five years, when roughly five meters of silt has accumulated (1 m/yr)(Ann Smith, Curator and Archivist Sherborne Castle, e-mail message to author, March 25, 2010). The cascade at Blenheim was recently restored at a cost of £1 million (John Forster, Archivist to His Grace the Duke of Marlborough, e-mail message to author, July 20, 2009). The repairs fixed leaks to the dam following the requirements of the Reservoir Control Act and the need to preserve Brown's aesthetic intent.

Today the lake at Coombe Abbey is about 80 acres and less than 1.4 meters deep throughout. Sedimentation of this large and shallow lake has long been a management issue. A small stream, Smite Brook, supplies water to the lake, and as a result of sediment deposition an island develops at the upstream end, obscuring the views down the lake from the house. Records from 1898 at Coombe Abbey indicate that the lake was ten acres larger and describe the ongoing sedimentation problems. The head gardener at the time Mr. Milton said he had to treat, "the narrow end of the lake, which had become so silted up by the inflow of a muddy stream that it had grown into an unpleasant-looking, evil-smelling swamp. In the place of dredging and distributing the mud on the surface of the land, which method was abandoned on account of the cost, canals were cut through the mud, and ridges were thrown up between them, two to three feet (0.6-0.9 m) above the level of the water area." The estate last dredged the lake in the 1980s. According to the park manager, Jonathan Taylor, the lake has a capacity of 244,706 cubic meters and the current total volume of silt is 206,018 cubic meters or 84% of the total capacity. The estate managers are considering short and long term measures to manage the silt, including dredging the lake and placing the dredging spoils on site, a cost of around £2 million pounds. In the long term, they envision the most viable solution to be a complicated partnership with a variety of landowners along the feeder stream requiring change to land use and agricultural practices.

The Wimpole Estate managers dredged two of the three lakes in 1994 and 1995 to remove trees, thickets, and reed beds and rebuild a dam at a cost of roughly £160,000 (Simon Damant, The National Trust, e-mail message to author, July 22, 2009). According to the property manager, willows filled the lower lake and the upper lake was filling with sediment and covered in reeds. Dredging at Wimpole removed 2 meters of mud from the four-acre upper lake and 1.2 meters from the lower one. The dredging spoils were spread across ten acres of field alongside the lake where they raised the ground level by 0.6 meters and became a danger for visitors and cattle (Goodwin 1996). Lakeside trees died when the water level of the lower lake decreased as a result of incorrect leveling and one-quarter of the lake went dry. Our field observations show that a sediment trap excavated at the upper lake intended to address silting probably increased sedimentation in the lake by triggering a headcut that progressed upstream, causing erosion and mobilizing sediment to the lake downstream. Initially, the sediment loading to the lake caused extensive algal blooms and offensive smells for the first two years, but this cleared up when the sediment settled. The upper lake is not currently being dredged because it was found to be home to a rare wetland invertebrate, water voles and an otter (Hearn et al. 2002).

The record of lake maintenance at Croome Court goes back to 1772, 22 years after construction, when Lord Coventry wrote to Brown that the lake was failing and, "I believe the roots of the Trees have been a chief cause of the fissures in the bank" (Stroud 1950, p. 60). He asked that repairs be made promptly because "all the enjoyment of Croome next summer will depend upon it" (Stroud 1950, p. 60). At Croome, one meter of sediment accreted in sixteen years accompanied by aggressive reed and *Typha* growth (Figure 23). The estate halted plans to dredge the lake in 1998 until the surrounding fields had been taken out of cultivation, bringing an end to the soil erosion that was the source of sediment to the lakebed that led to extensive growth of reed beds. While the growth of vegetation probably had some ecological benefits, it was completely opposite to Brown's vision of a mirror-like, open water surface. To restore the lake, the National Trust assessed all sources of sediment and pollution to the catchment (Hearn et al. 2002). They found there are many sources of uncontrolled sediment, including: cattle housing, rape and maize fields, and high numbers of sheep, and run-off from the M5 motorway. Even with a 70% reduction in fish stocking the lake would still be subject to nutrient pollution. The National Trust decided to create a new wetland, relocate the reed bed habitats, and filter the water flowing into the lake from neighboring fields and the M5 motorway. This wetland would need to be 3 hectares in size to be an effective filter, which would reduce the flow of water into the lake. The lake was dredged in 2006 to restore the quality of the mirror water and Brown's design.

Silting of the lake at Sherborne Castle has long been an issue, addressed annually by opening metal sluice gates in the dam to lower the water level and dredge the lake (Waymark 2001). In 1975 the silting was so extensive that the gates were replaced with a siphon, the cascade widened by two-thirds, and a silt trap constructed upstream (Ann Smith, Curator and Archivist Sherborne Castle, e-mail message to author, March 25, 2010). The silt trap is cleaned out every five years, and silt accumulates in the trap to the depth of about one meter every year. The history of sediment management at these four estates illustrates the challenges of managing ornamental lakes given the ecological, land use, and hydrologic forces at work.

3.4.4 Lake management for ecological value

Some recent biological studies recommend conserving Brown's lakes and other ornamental lakes because of their ecological value. In a landscape that has a long and extensive history of human settlement, conservation of 18th century ornamental lakes has significant aquatic macrophyte habitat value. The ornamental lakes support pondweeds (*Characeae*), which have been lost in many lakes due to changes in land use and eutrophication (Sayer et al. 2008). Copp, Carrington and Welsey (2008) recommended management of ornamental lakes for conservation of threatened crucian carp (*Carassius carassius L.*). They experimented with lake management by mitigating for nutrient enrichment and a heavily silted substratum using barley straw submerged in the lake as macroinvertebrate substratum and calcium carbonate particles to decrease organic matter (Copp et al. 2008).

The National Trust manages many Brownian water features and must balance preservation of historical landscape gardens with the ecological conservation value of the water features. They recommend that thick grass cover near ornamental lakes be thick grass so that it intercepts silt, and the lake water level be allowed to fluctuate with season, meaning higher water in the winter than summer (Hearn 2008). They suggest making compromises between clean edges with grass and allowing some shrub and tree vegetation and dead wood in the water to increase habitat value of the lake (Hearn 2008). Berrington Pool, a 17-acre lake is an example of a compromise between Brown's original designed lake with mirror-like reflections and clean grass edges and the conservation value of the lake (Figure 24). The pool was designated as a Site of Special Scientific Interest in 1983 under Section 28 of the amended Wildlife and Countryside Act because it is "one of the very few sizeable areas of open water habitat found in Herefordshire" (Natural England 2011). Lake managers do not remove bank vegetation, including great reedmace (*Typha latifolia*), reed-grass (*Glyceria maxima*), and lesser reedmace (*Typha angustifolia*)(Natural England 2011). Brown's island covered with oak (*Quercus robur*) is one of the only two heronries in Herefordshire (Natural England 2011).

These studies highlight one view of ornamental lake management, whereas others might take a different view of lake terrestrialization as a process of ecological succession. Hearn, Flanders and Phillips (2002) make the point that as lakes undergo infilling the resulting habitats have ecological value and in some cases this value may be higher than that of the un-sedimented lake. They point out that sediment in lakes is inevitable, and from an ecological point of view some artificial lakes and all natural lakes should be allowed to infill over time (Hearn et al. 2002). At the edges of lakes, sediment provides substrate for rooted aquatic plants and supports 90% of the biodiversity of a lake, and sediments release nutrients into the water that are important for plant growth (Hearn et al. 2002). They recommend not dredging when possible to avoid loss of archaeological and biological resources. The spoils are of little value to agricultural land, and there are legal and other constraints. Hearn, Flanders, and Phillips (2002) argue that lakes can be maintained via sediment control implemented at a catchment scale.

3.5 Conclusion

McHarg (1969) describes Brown's landscapes as design with nature and self-perpetuating. Our results demonstrate that these supposedly design with nature water features have required continuous dredging and vegetation removal, essentially counteracting the process of sedimentation that would alter the lakes over time as a part of spontaneous, local ecological processes. Brown's lake construction method does not indicate he foresaw dredging and other maintenance requirements. Our results demonstrate that Capability Brown's water features were not self-perpetuating, required maintenance, and that the designs did not differ in response to the local geology. Thus, the persistence of Brown's water features has probably related more to the long-term economic stability of estates than to Brown's ability to design with nature. As new Brownian lakes are built and existing lakes are maintained there is an opportunity to incorporate sustainable measures to decrease maintenance requirements and environmental impacts. Brown's water features are a designed aesthetic and should not be confused with ecological function or design, because given enough time the lakes would infill with sediment in the absence of dredging and vegetation removal.

Water was a main element in the 18th century English landscape garden and so is a significant aspect of historical preservation and continued enjoyment of Brown's historic landscapes. Brown's water features are a visual but not functional imitation of nature, specifically lakes and river bends, on a grand scale. They would probably not have the same aesthetic appeal if the water did not reflect the sky, if the lake and river banks were not trim and seamlessly blending into the grass lawn, or if vegetation blocked the view from the estate to the water or vice versa. The landscapes are highly manufactured, and if one looks past the winding curves of a Brownian lake at the dams and drainage systems, the construction and engineering becomes evident. Walking downstream past the *New River* section at Blenheim Estate, one finds the stream is much narrower and the meandering pattern more irregular. William Gilpin noted this contradiction in 1791 when he said, "An artificial lake has sometimes a good effect" but "you must always suppose it a portion of a larger piece of water; and it is not easy to carry on the imposition" (Hunt 1975, p. 340). The persistence of the water features is a testament not to their integration of ecological process but to ongoing human intervention to maintain these iconic landscapes, the enduring economic means of their owners, and the continued popularity of the aesthetic of the English landscape garden.

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Table 2. The dimensions of five dams designed by Capability Brown.

Site	**Length (m)**	**Height (m)**	**Notes**
Chillington Dam	-	12	(John Gifford, owner, email message Feb. 2010)
Harewood Dam	116	8	Earthen embankment is 10 m. wide
Petworth Dam	165	7	-
Sherborne Castle Dam	150	7	(Skempton 2002)
Wakefield Lodge Dam	210	8	-

Table 3. Water feature characterization and comparison with Stroud's (1950) assessment of landscape persistence and our assessment of water feature persistence through time. ○ – Brown landscape or water works in existence, △ – Brown landscape or water wholly or partly in existence, ● – Brown landscape or water lost, ✻ - Brown landscape created since 1950. A dash (-) indicates Stroud did not assess the landscape, a double dash indicates no response.

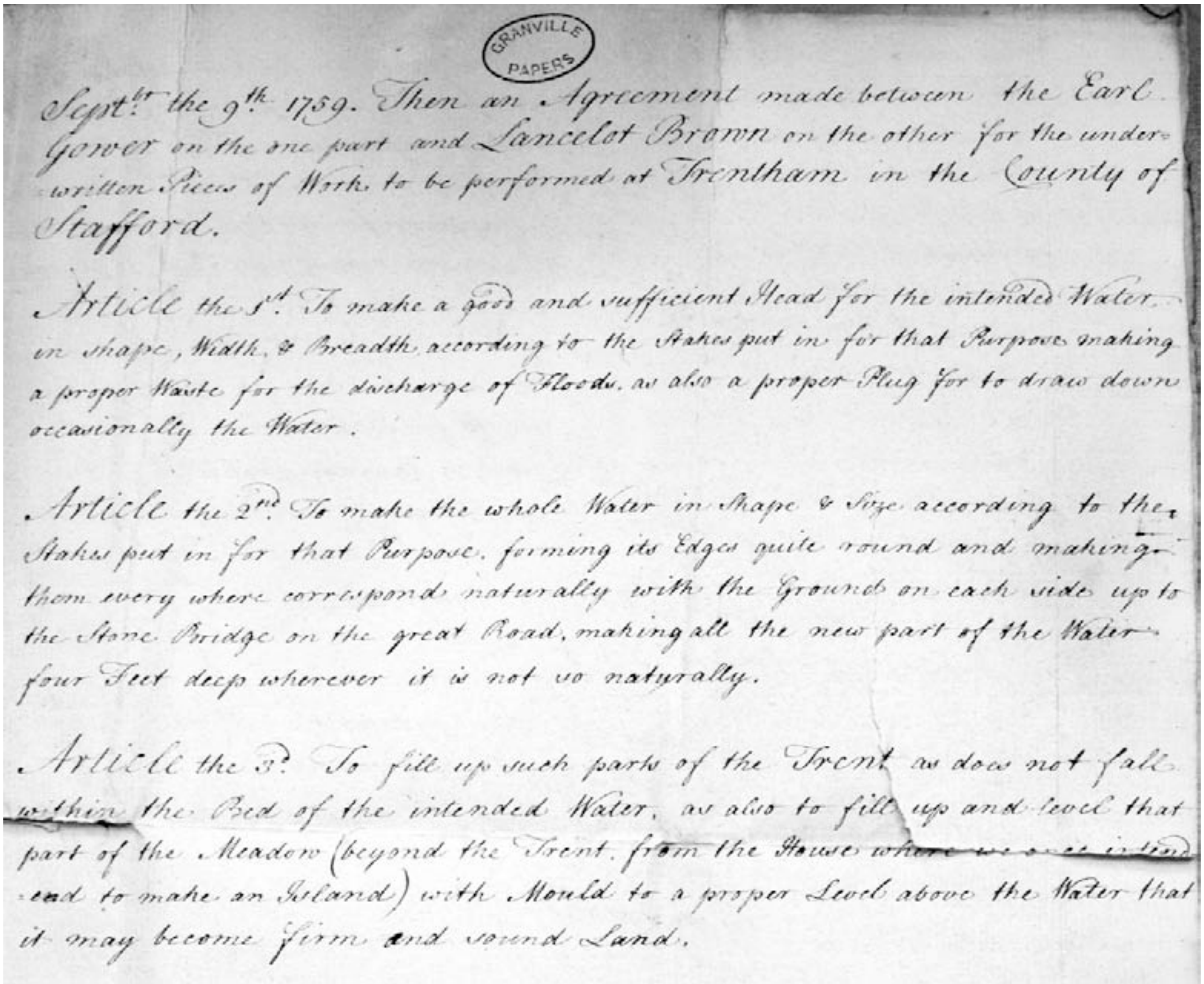
#	Estate	Date	Land-scape Status	Water Status	Mid-line length (m)	Dredge	Dredging Frequency	Source of Maintenance Information	Lithology
1	Addington	1781	●	○	236	--	--	--	mudstone, siltstone, sandstone
2	Alnwick Castle	1760	○	○	1149	NO	Not in last 30 years	Christopher Hunwick, Archivist Alnwick Castle	limestone, sandstone, siltstone, mudstone
3	Ashburnham Place	1767	○	○	1190	--	--	--	sandstone, siltstone, interbedded
4	Aske	--	○	○	223	YES	Dredged in 2005	Earl of Ronaldshay	limestone with subordinate sandstone and argillaceous rocks
5	Astrop	1762	-	○	378	--	--	--	mudstone, siltstone, limestone, sandstone
6	Audley End	1763	○	○	682	YES	Dredged in 1990s, annual removal of reed growth	Jenifer White, English Heritage	chalk
7	Benham	1775	△	○	517	YES	1 m. of silt accumulates in parts of lake	Sue Birley	chalk
8	Berrington	1781	○	△	467	--	--	--	mudstone, siltstone, sandstone
9	Blenheim Palace	1763	○	○	2173	YES	Dredged as early as 1892	(Green 1998)	sands, limestone, argillaceous rocks
10	Bowood	1757	○	○	1420	NO	--	Kate Fielden, Curator Bowood	muds, silts, sands
11	Brocklesby	1771	△	○	306	NO	--	Michael Day	chalk
12	Burghley	1754	△	○	1514	YES	Dredged 4 times at ~55 year intervals	Jon Culverhouse, Burghley House Preservation Trust	muds, silts, limestone, sandstone
13	Burton Constable	1759	△	○	1043	YES	Upper lake dredged	Dr, David Connell, Burton Constable Foundation	chalk
14	Castle Ashby	1761	○	○	1238	--	--	--	muds, silts, limestone, sandstone
15	Chatsworth	1760	○	○	785	NO	--	Stuart Bard Archivist	muds, silts, sands
16	Chillington Hall	1760	-	○	1229	NO	--	John Giffard	muds, silts, sands
17	Compton Verney	1768	△	△	1438	--	--		mudstone, siltstone, sandstone
18	Coombe Abbey	1771	●	△	2929	YES	First record of dredging in	Jonathan Taylor, Country Parks	muds, silts, sands

							1898, most recent in 1980s	Manager	
19	Croome Court	1750	△	○	1979	YES	In 2006 and 30 yrs. ago	Christopher Gallagher, The National Trust	muds, silts, sands
20	Doddington	1770	○	○	627	--	--	--	mudstone, siltstone, limestone, sandstone
21	Edgbaston Park	1777	●	△	378	--	--	--	sands, conglomerate, interbedded
22	Euston Hall	1767	●	●	1199	YES	dredging	Edward Wortley	chalk
23	Flamberts	1768	●	○	1269	--	--	--	chalk
24	Heveningham Hall	1782	○	∗	1519	NO	--	Kim Wilkie, Landscape Architect	gravel, sand, silt, and clay
#	Estate	Date	Landscape Status	Water Status	Mid-line length (m)	Dredged	Dredging Frequency	Source of Maintenance Information	Lithology
25	Himley Hall	1774	●	○	554	--	--	--	sandstone and conglomerate, interbedded
26	Kiddington	1740	○	○	745	--	--	--	sands, limestone, argillaceous rocks
27	Kimberley	1762	○	●	269	--	--	--	chalk
28	Kirtlington	1752	○	△	272	NO	--	Christopher Buxton	sands, limestone, argillaceous rocks
29	Longleat	1757	○	○	877	YES	every 10 yrs.	Dr. Kate Harris	limestone, sandstone, siltstone, mudstone
30	Luton Hoo	1764	○	○	2414	YES	--	Oonagh Kennedy	chalk
31	Madingley	1756	●	○	212	--	--	--	mudstone, sandstone, limestone
32	Milton Abbey	1763	△	○	489	--	--	--	chalk
33	Newnham Paddox	1763	●	△*	438	--	--	--	muds, silts, and sands
34	Nuneham Courtenay	1778	○	△	198	YES	Dredged in 1995, some lily removal	Doug Stephenson, Garden Manager	sandstone and muds
35	Packington Hall	1750	○	○	940	--	--	--	muds, silts, and sands
36	Paultons	1772	●	○	894	YES	every 20 yrs.	Guest Services, Paultons	sand, silt and clay
37	Petworth House	1751	○	○	653	--	--	--	sands, muds
38	Ragley	1778	●	○	443	--	--	--	muds, silts, and sands
39	Redgrave	1763	●	△	1195	--	--	--	chalk
40	Rothley	1765	○	○	1250	NO	Not in last 20 years	Richard Dickinson, Estate Warden	muds, silts, and sands
41	Rycote	1770	●	○	532	--	--	--	mudstone, siltstone, sandstone
42	Sandleford Priory	1781	●	○	197	--	--	--	clay, silt, sand. and gravel
43	Sheffied Park	1776	●	△	573	YES	silt trap northern end of lake	Andy Jesson, Head Gardener	sands, and silts interbedded

44	Sherborne Castle	1756	○	△	1474	YES	Silt trap built at upstream end, cleaned every 5 yrs	Mrs. Ann Smith, Curator and Archivist	sands, limestone, argillaceous rocks
45	Stoke Place	1771	-	○	384	--	--	--	clay, silt, sand and gravel
46	Stratfield Saye	--	-	●	--	--	--	--	clay, silt, sand and gravel
47	Syon (East Lake) (West Lake)	1758	○	○	484, 595	YES	West lake dredged on regular basis	Richard Melhuish	clay, silt, sand and gravel
48	Thorndon	1772	●	○	298	NO	clearing reeds only	Giles Thomas, Club Manager	sand, silt, and clay
49	Trentham	1759	●	○	1349	--	--	--	sandstone, conglomerate, interbedded
50	Ugbrooke	1761	○	○	1090	--	--	--	mudstone, siltstone, sandstone
51	Wimbledon Park	1767	●	○	593	YES	plans to dredge for sailing	Sim Comfort	clay, silt, sand and gravel
52	Wimpole	1758	○	△	454	YES	Dredged in 1996	Simon Damant, The National Trust	chalk
53	Wrest	1758	○	△	1045	--	--	--	mudstone, sandstone, and limestone

*Note in Stroud (1950) that Brown's sinuous lake was filled in the east of the house in 1870, before the OS map.

Figure 15. A section of Capability Brown's contract for construction of the lake at Trentham estate detailing how to construct the lake using stakes to outline the form and make the edges "correspond naturally with the ground on each side" (The National Archives 1759).



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Sept.r the 9th 1759. Then an Agreement made between the Earl Gower on the one part and Lancelot Brown on the other for the underwritten Pieces of Work to be performed at Trentham in the County of Stafford.

Article the 1st. To make a good and sufficient Head for the intended Water, in shape, Width, & Breadth, according to the Stakes put in for that Purpose making a proper Waste for the discharge of Floods, as also a proper Plug for to draw down occasionally the Water.

Article the 2nd. To make the whole Water in Shape & Size according to the Stakes put in for that Purpose, forming its Edges quite round and making them every where correspond naturally with the Ground on each side up to the Stone Bridge on the great Road, making all the new part of the Water four Feet deep wherever it is not so naturally.

Article the 3d. To fill up such parts of the Trent as does not fall within the Bed of the intended Water, as also to fill up and level that part of the Meadow (beyond the Trent, from the House where we once intended to make an Island) with Mould to a proper Level above the Water that it may become firm and sound Land.

Figure 16. Eastward (upstream) aerial view of the Heveningham lakes, before and after the creation of Brown's lake in the 1990s (source of images Kim Wilkie Associates).

Figure 17. Map of Brown's water features in England included in this study and the visual assessment of persistence through time. Site numbers correspond to Table 3. The extent of Quaternary glaciation in northern England indicated with a dashed line.

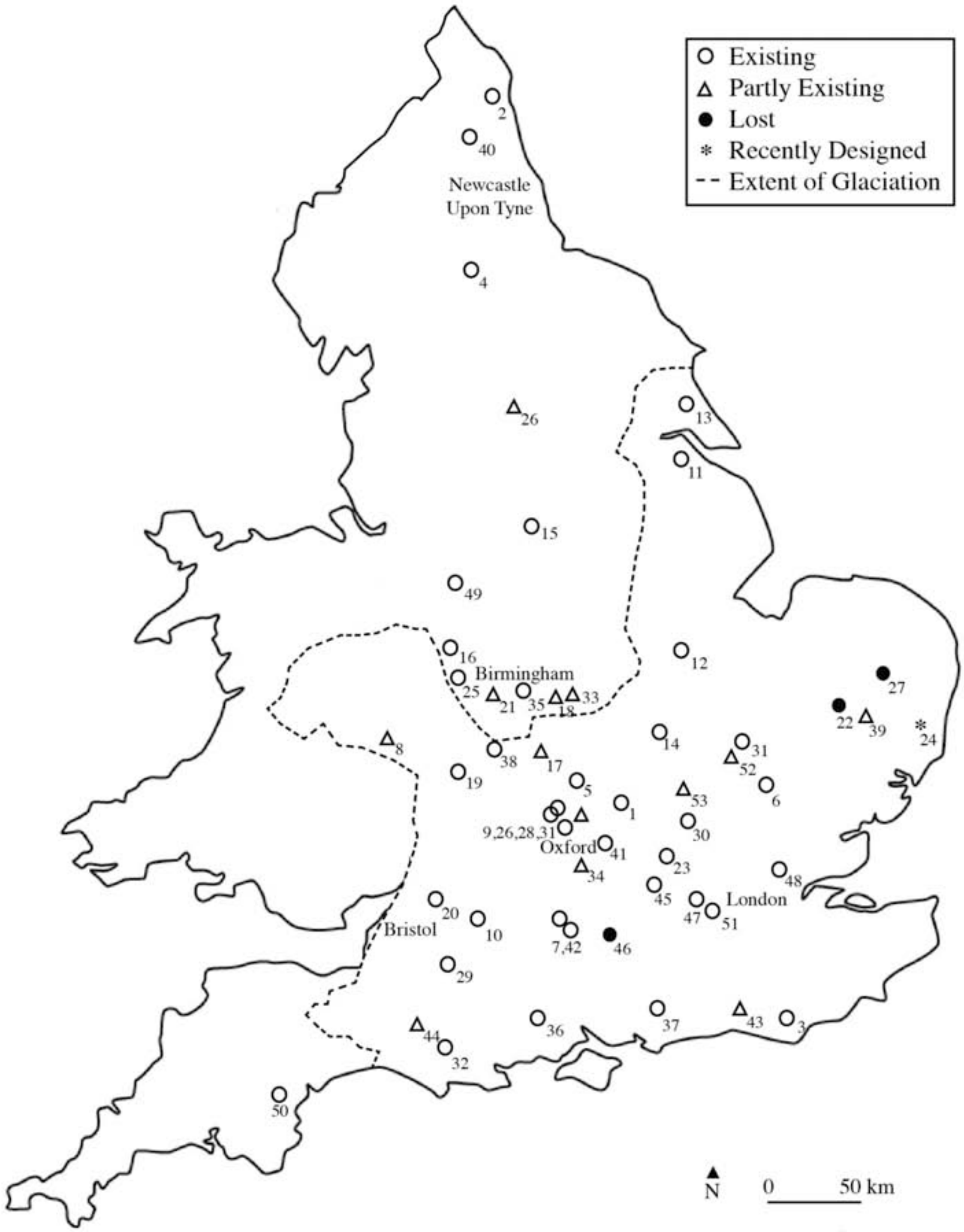
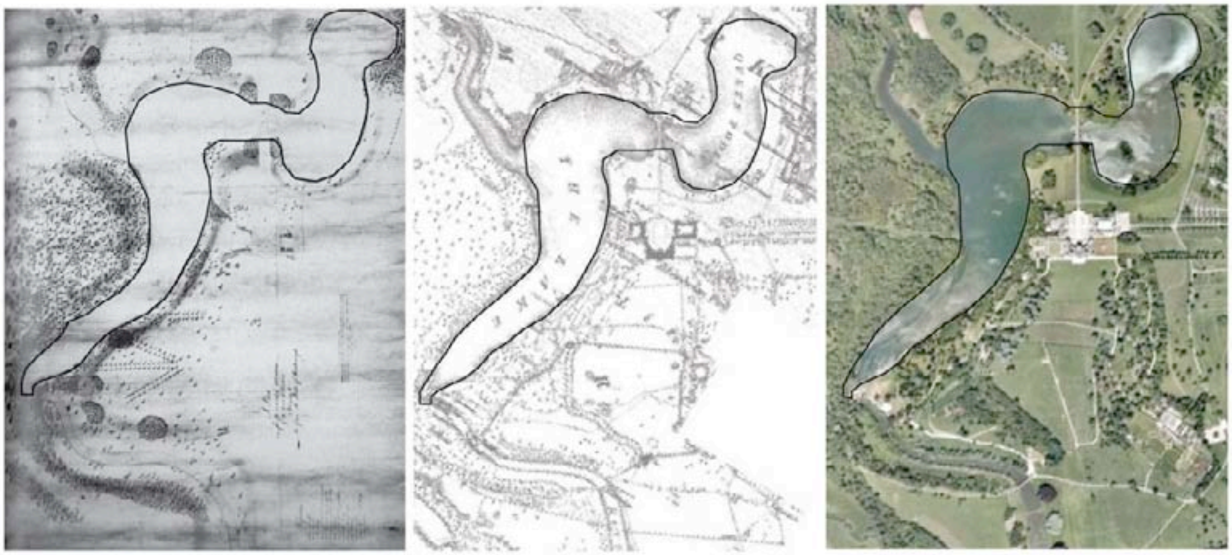
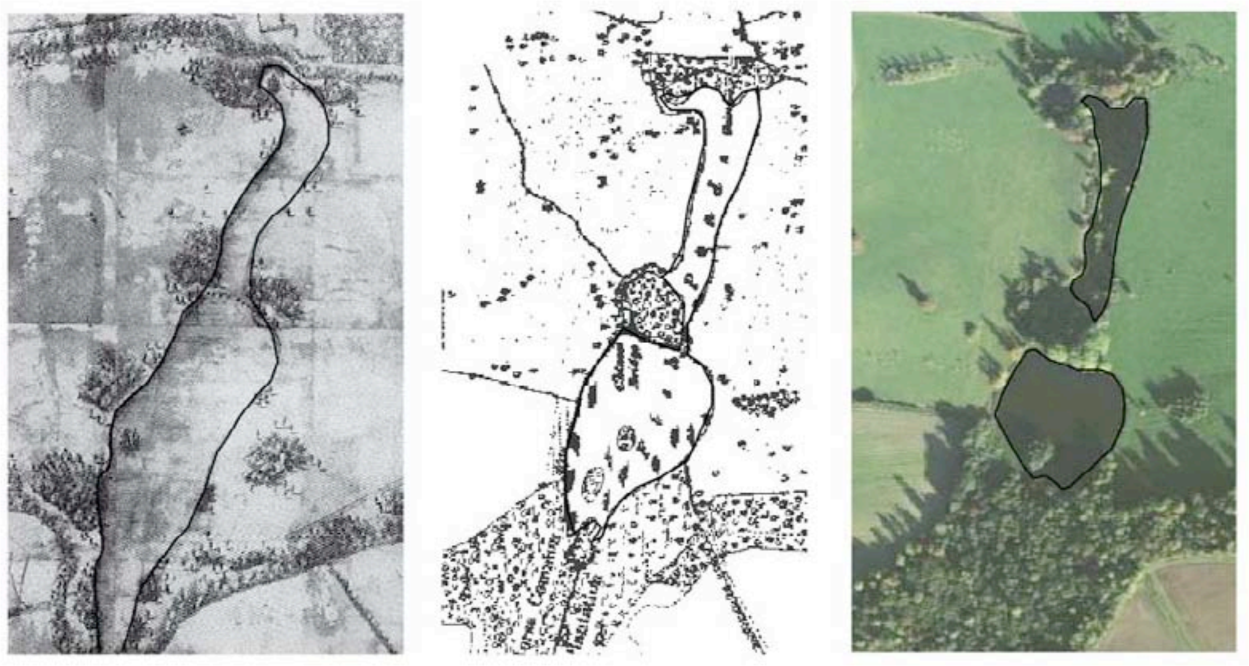


Figure 18. The water feature at Blenheim Palace, the first 19th century Ordinance Survey Map (b), and a 21st century satellite image shows (c), as outlined from Brown's 18th century plan (a), the lake essentially unchanged through time.



(a) (b) (c)

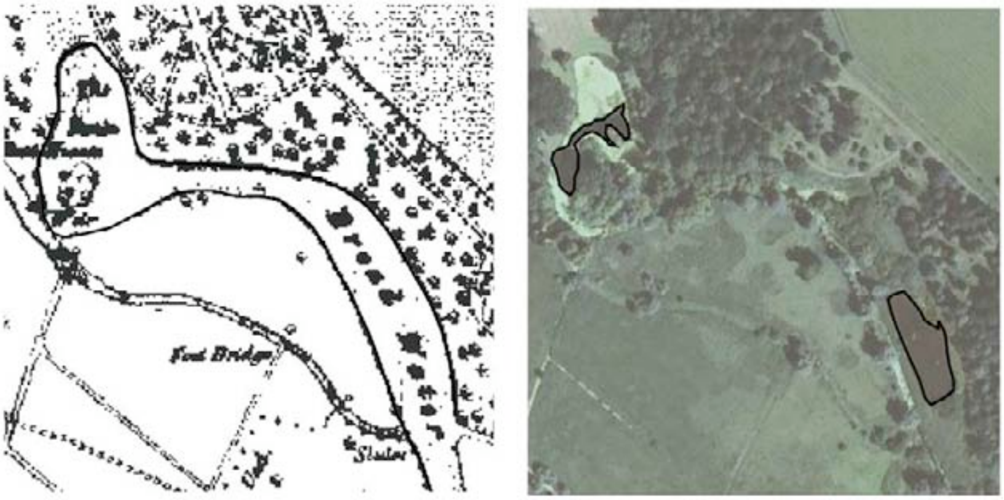
Figure 19. The water feature at Wimpole was depicted as a single long lake on Brown's 18th century plan (a), but as two separate lakes in the 19th century Ordinance Survey Map (b). By the 21st century satellite image (c), the area of open water had been reduced, despite dredging.



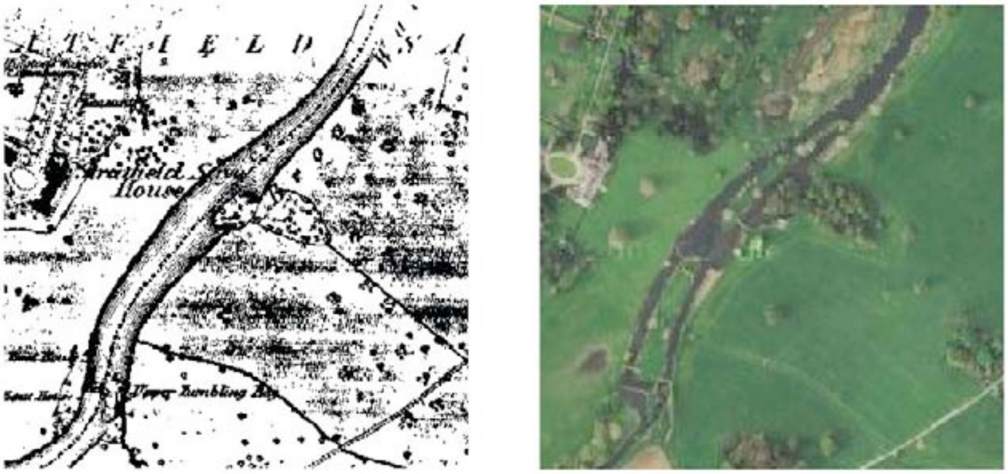
(a) (b) (c)

Figure 20. The “Broad Water” at Euston Estate and Stratfield Saye, and Kimberley Lake at Kimberley Hall, lived up to their names in the 19th century Ordinance Survey (a), but by the time they were captured in 21st century satellite image (b) sedimentation and encroaching vegetation had filled most of the formerly open water.

Euston Estate



Stratfield Saye



Kimberley

(a) (b)

Figure 21. Brown's landscape design for Wimbledon Park and Thorndon were considered not in existence by Stroud (1950) because of the development of golf courses and other land uses, but the Brownian lakes have persisted from the 19th century Ordinance Survey (a) to the 21st century satellite image (b) with no change.

Wimbledon Park

Thordon

a) b)

Figure 22. The plan for Horsham showing the former long, straight lake and river channel (light blue) and the proposed outline for a new lake (dark blue). The proposed waterfall in the center of the design appears to flow in the axonometric plan.

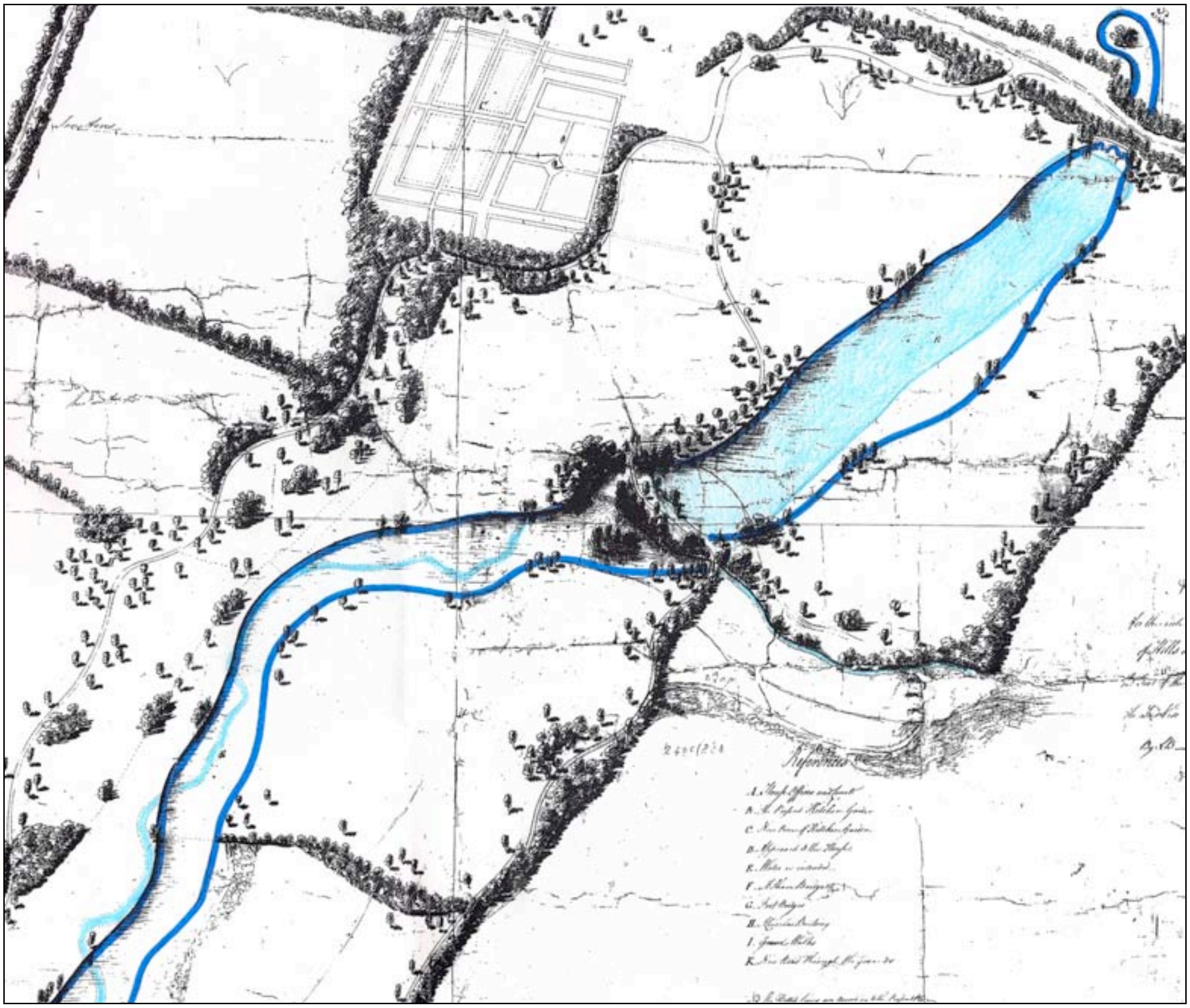
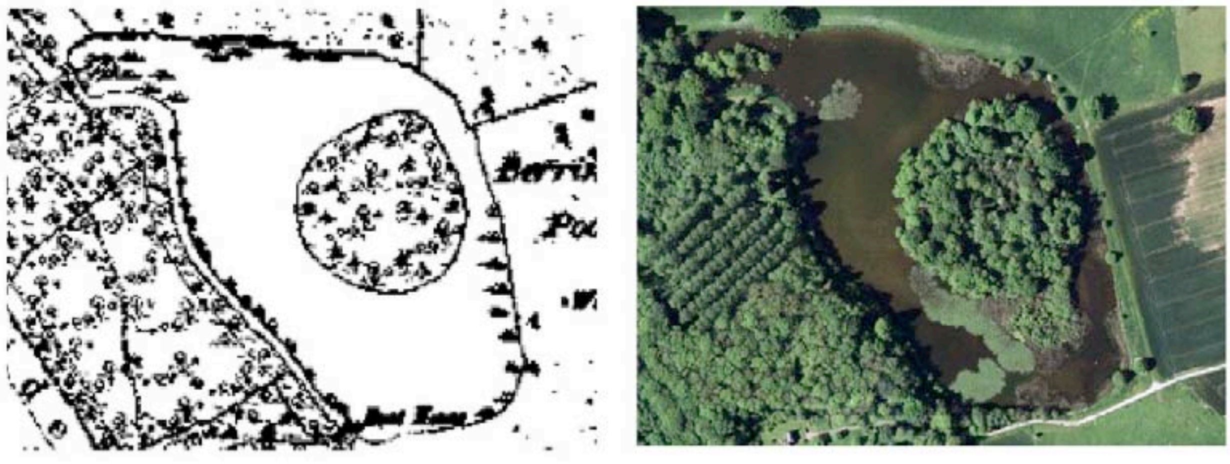


Figure 23. The lake at Croome Court was dredged between 1991 (a) and 2010 (b).

(a) (b)

Figure 24. Berrington Pool in 1888 (a) and in a 21st century satellite image (b) showing the reed growth in the southern end of the island for conservation value.



a)

b)

Appendix A. Sites not included

No Lake Constructed (21):
Ashridge (no water feature found)
Aynhoe (Turner 1985)
Beechwood (Turner 1985)
Belvoir (no work carried out, Turner 1985)
Cadland
Caversham
Cowdray
Cuffnels (Turner 1985)
Denham (Turner 1985)
Ditton
Elvenden
Highcliffe
Hill Park
Lacock Abbey
Langley
Sledmere
Southill
Swynnerton
Temple Newsam (James Lomax, Curator, Temple Newsam House)
Tottenham
Wotton

Not Brown's Design (2)
Adderbury (Nick at Adderbury)
Claremont designed by William Kent (Kim Kitson, Property Administrator, The National Trust)

Cascade or bank modification only (2):
Charlecote
Warwick

Not Found (10):
Branches
Digswell
Fisherwick (landscape demolished in 1810 prior to historic OS map)
Littlegrove
Lowther
Peterborough House
Radley
Thame
Tong
Youngsbury

Not Clear if Brown's water design (28):
Aske (no head of water built, Stroud 1950)
Ampthill (small pond, no record of Brown water feature)
Belhus (Stroud 1950)
Broadlands (Turner 1985, not clear if Brown modified river bend)
Burton Park (several lakes)
Clandon
Claremont (Charles Bridgman and William Kent)
Cole Green
Compton Wynnates
Corsham Court (lake designed by Brown, made by Repton, not clear if modified)
Ditchley (Chris Galloway, Ditchley Foundation)
Eaton (Turner 1985, lakes made later by John Webb)
Fawsley
Grimsthorpe (lake by John Grundy, Ray Biggs Grimsthorpe and Drummond Castle Trust)
Highclere (Turner 1985, lakes carried out by estate)
Knowsley Park
Leeds Castle
Melton Constable
Newton Park (called fish pond in historic OS map)
North Stoneham (Turner 1985)
Patshull (Stroud 1950, Turner 1985 credits the lake to Brown, but there is no statements about earlier lakes)
Pishiobury
Prior Park (Matthew Ward, Head Gardener)
Rise
Roche Abbey
Scampston (designed by Brown but built under owner's direction, Stroud 1950)
Stoke Park
Weston Park

Chapter 4

A River or a Fountain? Evaluating Three Urban River Restoration Projects

Abstract

In urban landscapes, river restoration projects are sometimes described as instream gardening or green pipes, implying little ecological value. To what extent do urban river restoration projects actually restore the ecology versus simply create attractive public spaces? To answer this question I compared three high-profile urban river projects based on an assessment of their stated objectives and standards for ecologically successful river restoration. I found that while the Cheonggyecheon stream in Seoul, South Korea, supports fish, and in places creates the illusion of "nature," it is best viewed as a fountain because of its artificial water source, steady flow, rigid banks, and impermeable bed. The South Platte River in Denver, Colorado, focused on recreation without significantly reversing degradation of the river's ecological functions. By contrast, the works on the Isar River, in Munich, Germany, combined ecological restoration with enhanced recreational opportunities and aesthetics. All three projects serve as a human amenity, but the Isar pushed traditional aesthetic ideals of nature into a new realm, and allowed people to find pleasure in connecting with the river, while giving it room to evolve naturally by way of sedimentation and erosion processes.

4.1 Introduction

The Cheonggyecheon project was completed in 2008 and is widely lauded as a successful urban design. Through daylighting of a stream the project created a human amenity and riparian corridor in the core of the city of Seoul, South Korea (Revkin 2009, Kang and Cervero 2008). The project includes natural features and opportunities for engagement with the environment. Others say the river is "far from natural… it flows through a concrete channel" (Normile 2010) and is an "artificial spectacle" (Cho 2010). Cheonggyecheon looks like a stream and follows the course of the former streambed, but it may be instructive to step back and ask whether it is a restored stream or the world's largest fountain? If projects like Cheonggyecheon are more accurately described as instream gardening, then the critique of restoration as an anthropocentric undertaking to promote human interests may prove accurate (Katz 1992). Alternatively, river-like fountains may improve human health, increase awareness of the value of nature, and contribute to a culture of nature (Light 1996).

Definitions of river restoration typically emphasize returning degraded ecosystems to a "pre-disturbance" state, or restoring natural functions that create wildlife habitat (Downs and Gregory 2004). However, numerous definitions have been proposed for river restoration, rehabilitation, revitalization, naturalization, enhancement, and related terms, generally emphasizing that it is usually impossible to return a river to a pre-disturbance state (e.g., Dufour and Piegay 2009, Wohl 2005, Gregory and Chin 2002, Rhoads et al. 1999, Brooks and Shields 1996, NRC 1992). Ecological restoration generally aims to reverse biotic change and move the system back to a more valued ecosystem, in terms of composition and function (Palmer et al. 2005, Findlay and Taylor 2006). Some question whether restoration is a viable option given the constraints of urban landscapes. As Findlay and Taylor (2006) stated, "Traditionally the ecological health of urban streams was given little attention relative to social and economic concerns" (p. 316). Urban streams have usually been simplified, the river disconnected from its floodplain, and streamflow regulated to prevent flooding. Restoration to a pre-disturbance state is unlikely given the need to protect infrastructure and human safety. However, many urban river restoration efforts do aim to restore ecological processes, and efforts are most effective when a watershed scale approach is adopted that addresses the altered flow regime, the floodplain is protected, and water quality impacts from sewage treatment and stormwater runoff is reduced (Bernhardt and Palmer 2007).

Recently, there has been an increasing effort to bring nature back into the city and design riverfronts in a way that accomplishes both improved recreational access and wildlife habitat (Eden and Tunstall 2006, Schanze et al. 2004, Tunstall et al. 2000). Urban river restoration is more expensive and more difficult than restoration in less populated places in terms of the constraints and lack of space to work with. Past studies evaluating river restoration show that restored rivers are well used and valued (Tunstall et al. 2000), project success is often based on site observations or positive public opinion (Bernhardt et al. 2007), there is little assessment of the social aspect of restoration (Chiari et al. 2008, Eden and Tunstall 2006), and despite challenges it is possible to evaluate both the ecological and social impacts as evident in Schanze et al.'s (2004) case study of twenty-three urban river restoration projects. In this study, I evaluated restoration success by compiling the project objectives and available ecological and social data before and after construction of three high profile urban river restoration projects. I included a social assessment since all three projects had objectives aimed at recreation, urban renewal, or flood protection and these need to be included with the ecological assessment to determine a project's overall success.

4.2 Methods

I compared the Cheonggyecheon to two other projects, the South Platte River Greenway in Denver, Colorado (US) and the Isar River Rehabilitation in Munich, Bavaria (Germany)(Figure 25). I selected these projects because they have all become vibrant public spaces within the urban landscape, but they conjure up different meanings of the word restoration. They represent a broad geographical spread but are all located in developed countries with advanced economies. I describe the history of each river project and the stated objectives. I first calculated what fraction of the objectives was ecologically focused. Next, I selected indicators, based on Palmer et al. (2005) standards of ecological success and compared the conditions before and after restoration using existing publicly available information and monitoring data, and by contacting project experts for monitoring data. The five ecological standards are: 1) a guiding image of dynamic state, 2) a measurably improved ecological condition, 3) a river system that is more self-sustaining and resilient, 4) no lasting harm is done during the construction phase, and 5) before and after assessment is completed and the data made publicly available (Palmer et al. 2005).

I selected eight ecological indicators from a huge array of potential indicators, because of their relevance to the five standards (Palmer et al. 2005, Woolsey et al. 2005). I scored the indicator value as zero if there was no change and awarded one point if the indicator improved or was completed, the maximum score was eight. This method is similar to Bernhardt et al. (2007) ranking of 317 river restoration projects based on three of the ecological standards set by Palmer et al. (2005). They scored projects by awarding points based on their effectiveness, with scores of a maximum 13 points for guiding image, 60 points for ecosystem assessment, and 16 points for ecosystem improvement (Bernhardt et al. 2007). Our assessment is more simplified, change or no change, which allows us to assess whether the ecological standard was achieved without having to determine the degree of effectiveness. I first evaluated the design plans and objectives to see if a dynamic guiding image was implemented. A dynamic guiding image is not an unattainable goal to reach a historical river state, but one that takes into account the impacts to the hydrology and geomorphology of a particular site and moves the river along a vector of ecosystem improvement (Palmer et al. 2005, Findlay and Taylor 2006). Fryirs and Brierly (2009) recommended a "place-based guiding image" and restoration designs that focus on how a river works and adjusts, not how it looks. The guiding image can be based on historical information, reference sites, or models, but the key is that the image is not single or fixed and should consider watershed scale issues in addition to local considerations.

Next, I assessed the source of the streamflow in the project and whether the flow was managed to mimic the natural flow regime (Poff et al. 1996). I compared water quality using data available for each project: biological oxygen demand (BOD), nitrates, Escherichia coli (E. coli), phosphorous or selenium. Lower levels of BOD indicate a cleaner more pristine stream condition and lower levels of E.coli indicate a reduced risk of sickness as a result of ingesting water with fecal coliform bacteria. High phosphorous can lead to eutrophication and reduction of dissolved oxygen. Excess selenium associated with irrigation of soils containing selenium, coal-fired power plants, or mining activities can be toxic to aquatic life. I assessed the condition of the streambed and banks, as an additional indicator of ecological condition, because it provides the structure for aquatic habitat and, along with streamflow, is one of the most constrained river dimensions in a city. The most direct measure of ecological improvement was the change in the number and diversity of aquatic species. Determining whether the river was more self-sustaining post project was based on the change in maintenance requirements. No harm done during the construction was evaluated based on the removal or damage of pre-existing native vegetation. Finally, I describe the social impacts of the projects with respect to the project's objectives. I did not score these social criteria as there was a lack of data and most data was observational.

4.3 Results

4.3.1 Cheonggyecheon

Project description

The capital city Seoul developed along the Cheonggyecheon (drainage area 51 km, river length 11 km) in the 14th century during the Joseon Dynasty. It was an ideal placement according to the principles of *feng shui* with a west to east flowing river valley flanked by mountains to the north and south. When Seoul became the capital of Joseon, the stream was occasionally dredged for flood control (Park 2007). In the early 20th century, Cheonggyecheon was covered from Taepyeogno to Gwangtonggyo to protect public hygiene and allow road expansion for transporting military goods under the Japanese colonization (Park 2007). Clearing the slums and building a gigantic boulevard over the buried creek was one of the symbolic achievements of the Mayor Kim Hyeon-ok, whose nickname was bulldozer under the military regime in the 1950-70s (Kwon 2009). As South Korea recovered from the Korean War and Seoul grew into a major international city, the stream in its heart became more polluted, neglected, and flanked by slums. In the late 1970s, a double decker elevated expressway with 14 lanes was built on top of the boulevard. The central business district bisected by this expressway became a decayed urban core (Kim et al. 2005).

The Cheonggyecheon restoration project was championed by Lee Myung-bak, former CEO of Hyundai Construction Corporation. Myung-bak promoted the project in 2001 during his successful bid for mayor of Seoul, and completed it in 2005 at a cost of $281 million U.S. dollars (Table 4). In 2003, a flood in the downtown area added urgency to the construction of the 6-km river project. Construction of the project was a massive engineering undertaking that entailed removing the expressway, exhuming the creek bed in sections, building a completely new channel in other sections, and rebuilding historic bridges (Figure 26). Demolition of the freeway occurred a mere 25 years after its construction, and remnants of the former roadway are visible in three support piers deliberately left in the new channel as reminders of the project history. Half of the four project objectives focused on the stream ecology, but the first objective was restoration of cultural and historical heritage (Table 4). The objectives are aggressive, succinctly worded, and broad; for example, the second objective is to, "bring back the ecosystem in the heart of the city" (Noh and Hwang 2010). The objectives focus on a fixed appearance of the Cheonggyecheon without taking into consideration watershed scale restoration.

Ecological assessment

Cheonggyecheon translates to creek of clean valley, but the water flowing through the channel is not the Cheonggyecheon and is not always clean. Water pumps transport 98,000 m^3/day uphill along 20 km of pipe from the Han River and 22,000 m^3/day from groundwater leaking into underground subways to the project site to supply water to the channel 24 hours a day (Table 5, Kim et al. 2005). Plans to pipe water from the upper reaches of the Cheonggyecheon and allow the water to flow in the restoration project were abandoned because implementing it would have slowed down construction, and the flow is highly seasonal: 60% occurs in the monsoon season from June to August and less than 10% from December to February, thus the stream would dry to a trickle in the winter (Cho 2010). Low flows were seen as unsuitable for an urban park and inconsistent with public preferences for a consistent, medium water level (Whittaker et al. 2005). The water quality monitoring pre and post project show a decrease in the biological oxygen demand (BOD_5, Kim et al. 2006). However, the Ministry of Environment's water monitoring system warned people to be careful of their recreational activities in the stream due to occasionally high levels of E. coli that exceed the water quality standard for water recreation (Song 2010).

The Cheonggyecheon projects significantly increased the number of species from 98 before the project to 788 one year after the project, with a six-fold increase in fish species and a seven-fold increase in macroinvertebrates (Table 5, Noh and Hwang 2010). The degree to which Cheonggyecheon provides habitat for native versus exotic species has been disputed, but the plantings along the stream are mostly native (Lee 2010). Green algal blooms appeared in the Cheonggyecheon every year since 2007 due to high nutrient levels in the source water from the Han River. In response to public displeasure with the appearance of algae and smell of the water, the city now pays thirty maintenance workers to mechanically remove algae from the bed twice a month (Yu 2009); equivalent to 2,100 workers and $68,000 per year since 2007 (Hong 2009) (Figure 27). The annual pumping cost to maintain the water flow is $8 million US dollars (Cho 2010). The project had a low level of overall success in meeting the five standards for ecological river restoration (Table 5).

Social assessment

The social benefits of the Cheonggyecheon involve recreation and open space in the city, political gain, and urban renewal. In the first three months the project was opened, more than 11 million people visited, and within three years more than 71 million (Chung 2008). Since then, visitation has decreased slightly, with 28 million in 2006 and 22 million in 2007 potentially due to the odor and green algae (Chung 2008). A survey of visitors during the grand opening ceremony showed that 98.6% of respondents were satisfied with the Cheonggyecheon restoration (Seoul Development Institute 2006), and another survey indicated that 82% of people used the site for recreation, with only 5% and 1% using the site for experiencing ecology and history, respectively (Seoul Development Institute 2006). In addition to the visitor satisfaction and high visitation numbers, Seoul Mayor Lee Myung Bak rode a wave of popularity surrounding the project to the presidency of South Korea in 2007 by the largest margin in Korean history (Cho 2010). Cost-benefit ratios also showed a positive outcome from the project (Lee 2005, Seoul Development Institute 2006). Finally, Cheonggyecheon was an urban planning project to renew downtown Seoul. It was a symbolic move, referencing Korean historical and natural heritage by restoring a critical water element in the *feng shui* relationships that guided the city's original siting and reclaiming historic stone bridges, sometimes in new locations due to auto-traffic flow patterns (Shin 2009). The design elements reinforce a narrative of national identity, embedded in the city matrix and experienced sequentially by moving through the linear park.

4.3.2 South Platte

Project description

From its headwaters in the Rocky Mountains, the South Platte River runs south to north through the capital city of Denver, Colorado (drainage area 12,400 km, river length 18 km). The city of Denver developed in the 1850s, at the confluence of the South Platte River and Cherry Creek. In the 1960s, the river served as a railroad corridor, industrial area, trash dump, and water source for private residents, agriculture, and industry. Two floods on the South Platte spurred the idea for the Greenway. In 1965, a devastating 100-yr flood caused $300 million in damage, and was followed by a smaller but still damaging flood in 1974 (WWE 1984). Roughly $75 million has been spent over the past 36 years creating the greenway to improve flood conveyance, and to create a recreational boating amenity and pathway along the river (Figure 28).

Joe Shoemaker, then Republican State Senator, and Democratic Mayor Bill McNichols championed the South Platte project and used $2 million in federal funding to jumpstart the greenway. The planning began in the 1970s, when Shoemaker appointed an eight-member panel, the Platte River Redevelopment Committee (PRDC) to set project objectives. The members were chosen to have a diverse range of age, ethnicity, political views, geography, and gender (Urbonas and Shoemaker 2002). Two of the five project objectives (40%) focused on ecology although they included both ecological and social goals and the prioritization unclear. The first objective was to reclaim the river environmentally and make it a "recreationally boatable amenity", but only within a 16.5 km stretch (Urbonas and Shoemaker 2002). The second objective was to create open space parks and natural areas throughout the river in Denver. The first park to be built (in 1974) improved boating passage and created a riverside park at the confluence with Cherry Creek. In 1976 The Greenway Foundation a private corporation replaced the PRDC and in 2000 the mayor created the South Platte River Commission, which recommended managing the river to sustain a variety of human uses and restore it to support a continuous wildlife corridor (CDM 2010, South Platte River Commission 2000).

Ecological assessment

Under natural conditions, the South Platte streamflow peaked in late spring and early summer from snowmelt runoff, receded by July, and then remained at low levels from August through April. "Platte" translates from French to flat or dull, likely reflecting the sluggish low-flow during most of the year before extensive river modification. Today, trans-basin water transfers from the Colorado River basin, releases from reservoirs, and the discharge of treated wastewater have led to a more even hydrograph over the year (Strange et al. 1999). The average daily flow is 16l cubic meters with effluent flow representing up to 90% of streamflow in dry months (Woodling et al. 2006). The minimum streamflow was increased to 4.25 cubic meters per second (cms) in 1995 to "protect habitat and recreational uses," and longitudinal barriers to navigation and fish passage have been removed (City of Littleton 2010). Due to public investment in wastewater treatment and improvements in the control of point sources of pollution to the river due to regulations (Federal Water Pollution Control Act 1972, National Pollutant Discharge Elimination System), the overall trend is improved water quality post-project (2001-2009): decreases in nitrate levels, no change in selenium or phosphorous, and decreases in E. coli levels through time (Novick and Russell 2010). Improvements in water quality in the South Platte River as a result of the greenway project may be masked by the greater effects of improvements in water quality resulting from the point source regulations (J. Novick, personal communication, February 14, 2011). However, the river is sometimes unsuitable for direct water contact recreation due to E. coli levels and poor water quality degrades aquatic habitat.

Historically, the South Platte River channel was wide (450-750 m.) and shallow with multiple channels. It was sand-bedded, with shifting sandbars and a largely unvegetated floodplain. With increasing agriculture diversions, less frequent flood scour, and irrigation return flow since the late 1800s, the river became a single thread channel with a narrower channel width. Riparian trees, mainly cottonwoods (*Populus deltoides*) and willow (*Salix spp.*), established in the active channel bed (below mean high water) increasing hydraulic roughness and trapping sediment, in turn constricting flow to a narrower width and inducing incision (Nadler and Schumm 1981). Exotic riparian vegetation such as the Russian olive (*Elaeagnus angustifolia*) that profit from the altered flow regime replaced native vegetation (Strange et al. 1999, Table 5). There was limited pre-project data on fish species and no pre-project data on macroinvertebrates. Generally for the entire South Platte River, the native fish species are declining and nonnatives are increasing due to the modified flow regime (Strange et al. 1999). In the Denver urban area the fish communities are dominated by suckers, a family of fish that can tolerate degraded water quality, and trout are stocked for fishing (USGS 1998). Post project the macroinvertebrate diversity declined from 1997-2003 possibly due to metro-scale impacts from increased development (Rapid Biological Assessment, DEH 2003). There was also no data on the riparian vegetation pre project so it was not possible to assess if harm was done during the greenway construction. The project had a low level of overall success in meeting the five standards for ecological river restoration (Table 5).

Social assessment

More than 48 kilometers of hike and bike paths were constructed along the river and more than 12 parks line the banks of the river, meeting two of the projects objectives (Table 4). The Greenway project received numerous awards as a successful urban design and public space, and is widely considered to be the first greenway project in the nation (Project for Public Space 2010, Spirn 1984, Searns 1995). There are not quantitative studies of the use, but the director estimates that… According to the Executive Director of the Greenway Foundation, the greenway is used recreationally by thousands of urban citizens on a daily basis for trail and instream uses (J. Shoemaker, personal communication, February 5, 2011). On a hot summer day, the confluence of the South Platte River and Cherry Creek is packed with people enjoying the river and using it like a beach. The area surrounding Confluence Park has increased in property value with the addition of high-end residential lofts in converted warehouses and industrial buildings.

4.3.3 Isar

Project description

The Isar River flows down from the Alps to Bavaria's capital city, Munich (drainage area 2.814 km, river length 125 km). Until the 19th century, the Isar River was a free flowing braided river system with a wide alluvial corridor and low flows in the late summer, when the water infiltrated the gravel bed and banks. In 1920, the river was fixed in a 50 m. wide trapezoidal channel to accommodate hydropower and allow development along the riverbanks (Binder 2006). The former riparian corridor was converted to grassland and maintained for soccer and other sports. Irregular gravel banks were replaced with steep banks armoured with large stones and concrete. Access to the river became difficult and dangerous. Channelization of the river required the installation of small weirs to prevent down cutting of the riverbed, interrupting longitudinal connectivity. In the 1950s, a dam was built upstream to control floods.

The idea for returning the Isar to a natural state, called the "Isar Plan" began in the 1980s when the hydropower plant applied to extract more cooling water from the Isar river and in reaction an interdisciplinary council study group composed of ornithologists, canoeists, hunters, and other groups formed (Schanze et al. 2004). The group was supervised by the Water Conservation Bureau, and when the river project became a political platform an expert planning group was assembled by the City of Munich and the Munich State Office for Water Management composed of water engineers, landscape architects, city planners and biologists. The planning group established the renaturalization objectives: four of the six objectives (66%) address the ecology: the second objective focuses on the river landscape and the third "restoring the ecological functions" (Table 4, Arzet and Joven 2009). A dynamic guiding image was established through historical analysis of the channel and selection of a reference site at Flaucher (Arzet and Joven 2009). Flaucher maintained its floodplain, open gravel banks and alternating gravel bars. This area served as a guiding image (leitbild) for the restoration design. The Isar River project began in 2000 and first restored a reach upstream of the city and then continued the project in the downtown area. The upper reach was in the property of the State of Bavaria, making costly land acquisition not a factor. In total, 8 km of the river within the city was at least partially restored to the original alpine character over the decade, at a cost of $38 million (Schanze et al. 2004)(Figure 29).

Ecological assessment

The flow regime of the Isar is still dynamic despite the reservoir near its headwaters. The river name derives from two Celtic words: *ys* meaning fast or torrential, and *ura* or river. Another interpretation of *ys* may mean low as well as high, and probably describes the rapidly changing water level in the river. Snowmelt from the river's alpine catchment dominates the hydrograph, paralleling the snowmelt hydrology of the South Platte River, albeit with higher precipitation and runoff. To benefit aquatic life, the project increased minimum flows from 5 to

15 cms, while still diverting 60-70 cms into the 6 km long hydropower canal (Table 5, Schanze et al. 2004). Additional wastewater treatment plants were built on the upper Isar, and 17 plants upgraded with UV disinfection capabilities that run for six months out of the year (15 April to 30 September), a costly ($37 million capital investment) but effective method to improve water quality for instream recreation and aquatic life (Zinsser 1999). The new treatment reduces the bacteria loads by about half during normal flow, but not during floods (W. Binder, personal communication, September 24, 2010).

An overarching principle of the design was to give space back to the river, allowing it to meander in a floodplain equivalent to the area inundated by the 100-year flood, and the area was expanded from 1600 to 2600 hectares (Binder 2004, Matthaei et al. 2004)(Figure 29). Paved banks (7000 m) were replaced with planted embankments, and the removed bank protection was broken down to gravel and supplied back to the river as bedload. Flat ramps with stone rocks in a honeycomb arrangement were a designed to control the grade, permit fish passage, add habitat complexity, and contribute to the morphological development of the riverbed (Figure 30). A Before-After-Control-Impact (BACI) study design was implemented to study the geomorphology and instream macroinvertebrate fauna pre and post restoration. The vertical heterogeneity of the bed, measured along random transects, increased post restoration and is associated with greater heterogeneity in stream velocity and other microhabitat parameters (unpublished data, Dr. S. Diehl, personal communication, April 10, 2011). Macroinvertebrate abundance, diversity, and functional group abundance (total abundance, number of taxa, Shannon Diversity Index, Shannon evenness, and abundance of EPT taxa, grazers, collectors, predators, detritivores, and shredders) showed increased or positive improvement post restoration (unpublished data, Dr. S. Diehl, personal communication, April 10, 2011).

The river requires little maintenance, and the channel can reshape itself, eroding banks and adding large wood, which forms valuable aquatic habitat. The dynamic process of bed migration provides habitat for fish spawning and bird nesting on gravel banks (Binder 2004). The existing vegetation, especially the trees, was carefully documented, and construction attempted to avoid disturbing it. When vegetation disturbance was unavoidable, valued vegetation was transported to already-restored sites minimizing the harm done during construction. The floodplain was seeded with a mixture of grass and flowers harvested from grassland along less disturbed reaches upstream. The project had high level of overall success in meeting the five standards for ecological river restoration (Table 5).

Social assessment

A survey was completed on landscape aesthetics and recreational use prior to the Isar project, but no post project data was found (Nohl 1998). The survey data show that the most common activities are lying, sitting and resting (15%) followed by walking (12%) and cycling (11%, Nohl 1998). The study also found that the value of the water generated for electricity at the Flaucher weir was equivalent to the annual recreational benefits of the water (Nohl 1998). There were qualitative statements from project leaders regarding the social impacts of the project. Dr. Joven, Director of the Munich Water Authority, commented that people “like the look of the natural drops and like to play on them.” The Flaucher section with wide gravel banks is so popular that more than 30,000 people have been counted there in one day (Munich Water

Authority). Before the project the motto for recreating in the Isar River was, "sunbathing is tolerate, swimming is forbidden" because of impairment due to E. coli (Munich Water Authority 2010). This was especially the case in the summer when there was less dilution from streamflow and more people wanting to recreate in the water. Following the project's enhanced UV wastewater treatment, the Isar is now considered safe for swimming during the summer from April to September (Munich Water Authority 2010).

4.4 Discussion

It was not possible to expand the Cheonggyecheon stream corridor in Seoul, where the channel was already lined with high-rise buildings, or on the South Platte in its built-out sections. Cheonggyecheon is within the most densely urbanized context and is the most artificial design with low ecological success (Table 4). Seoul is the only city in this study that is designated as a mega-city—it is the 22nd most populous city in the world (UNPD 2009). It was the most expensive project completed over the shortest timeframe, and social considerations not ecology seem to have taken priority. The existing infrastructure and population density in the city clearly limited the restoration potential, but opportunities to bring nature back into the city could have been more holistic and may have required a longer timeframe. In particular, the decision not to use the Cheonggyecheon stream water, but to pump water uphill from the Han River, and the use of a narrative instead of a design based on ecological processes reinforced the focus on creating a human amenity. The water feature has some ecological value, compared to the elevated expressway, and it may be a first step towards building a culture of nature.

The South Platte River character prior to the greenway differs drastically from the braided, seasonal stream of the past. The South Platte River represents a new ecosystem state designed by humans as a recreational amenity with an underlying main function for flood conveyance. Restoring channel forming processes was not a priority and the project had low ecological success relative to the other two (confusing two statements). The lack of monitoring data may be explained by the fact that monitoring restoration outcomes was not stressed until recently, and the project pre-dated most urban restoration efforts and was seen as a recreational greenway (Bernhardt et al. 2005). Another explanation may be that it is more difficult to find monitoring data for projects that started more than thirty-five years ago. The Cheonggyecheon and South Platte River projects both feature flat-lined hydrographs, with artificially elevated dry season flows. Both carry waters imported from out-of-basin, but the hydrograph modification and proportion of imported water are relatively larger in the Cheonggyecheon. To alter the flow regime of the South Platte and encourage channel-forming processes, as in the Isar, would require long-term planning to remove infrastructure from the floodplain in upstream reaches to allow the river room to be dynamic by way of sedimentation and erosional processes.

The Isar River was the most natural, with elbow room to erode its banks and flood its riparian corridor, driven by higher flow releases from the upstream dams designed to mimic natural flood effects. The Isar attempted to recreate the natural flow regime within the constraints of water diversions and flood conveyance, and the water quality meets stringent bathing water standards set by the Bavarian State Office for Water Management. However, even this ecologically successful project did not have publicly available information on the ecological monitoring that was conducted. The Isar project incorporated natural river processes into the city while accommodating for human use. Of the three cases it was the least expensive and the floodplain was not developed upstream of the city. Additionally, measures to improve the ecology, such as increasing the gravel banks were simultaneously seen as a way to improve the recreational opportunities. It was the only project of the three to use a dynamic guiding image, and most closely mimicked natural processes, illustrating how environmental and social objectives can be accomplished with the same design moves and do not need to be conflicting.

4.4.1 Perceptions of an ideal river

Positive public opinion and site observations are the main factors used to judge a project's success and these are both aesthetic assessments (Bernhardt et al. 2007). The design for the Isar, unlike the Cheonggyecheon and South Platte does not conform to typical public aesthetic preferences for a river. The aesthetic preferences of our target species, humans, is important and people generally define a river based on their personal experience, which reflects the landscape around their homes, their cultural beliefs, or their field of study (Taylor and Stokes 2005). Usually, our collective vision of an ideal river does not match an ecologically healthy river with scrubby riparian vegetation, eroding banks, inconsistent flows, and wood in the channel, all characteristics of a dynamic river system. Past studies show that even legal definitions of rivers derive from ideals about what a river "should look like" and may not fit the local environment (Taylor and Stokes 2005). In the Isar project the aesthetic ideals did not drive the rehabilitation. Choice of the *Flaucher* as the *leitbild* probably made the project more acceptable to the public because it was already a valued place for recreating and the only location where bonfires were allowed. Fortunately, it also embodied ecological restoration goals of a dynamic river corridor. The guiding image was not copied across the project reach, but rather informed the geomorphic and hydrologic design.

Aesthetically, the Isar does not have a consistent water flow year round, but varies from winter to summer. The water is not always clear (due to turbidity associated with early snowmelt runoff) and the banks are shrubby, not grassy as most people seem to prefer (Appleton 1975, Chin et al. 2008), and as created along sections of the South Platte Greenway. The Isar project allows for large wood in the river, despite the preference of most people for channels free from woody "debris" (Wohl 2005). Finally, the restoration allows the river channel to be active; streambanks erode, gravel bars shift, and there are multiple channels, contrasting with the widespread cultural preference for stable, single thread meandering channels (Kondolf 2006). After a flood in 2005, gravel islands were eroded or moved, pools were created along the stream edges, and large wood that floated into the reach was allowed to remain to add habitat complexity and serve as refuge for juvenile fish.

4.5 Conclusion

In this case study I focused on the ecological change resulting from the three urban river projects to answer the question of whether they are best viewed as rivers or fountains. I found that even in mega-cities like Seoul, the river project included ecological objectives although only accomplished a low level of success in reaching them. By comparing the projects, a distinction became apparent, between ecological restoration and using ecology as a foundation for a design intent. Resurrecting a stream from underground but filling it with pumped water

(Cheonggyecheon) or creating a recreational park along the river (South Platte) does not exemplify letting nature take its course, but rather attempts to add social benefits with fringe ecological benefits. The Isar project is still far from letting nature take its course, and the river was not restored to its original pre-disturbance condition, yet it was moved the furthest towards its former ecological complexity of the three projects and had the most success in meeting the project's ecological objectives while fostering an appreciation for and understanding of the dynamism of rivers. The project adopted a watershed scale approach to the altered flow regime, widened the floodplain area, and improved water quality through enhanced wastewater treatment, all measures of effective urban river restoration (Bernhardt and Palmer 2007).

When judging the overall success of the projects, the social change in addition to the ecological change needs to be considered (Findlay and Taylor 2006). Many of the project objectives were socially focused; however, assessing social change was challenging because there was a lack of available data. This suggests a need for more evaluation of the social impacts of river restoration projects, especially in cities (Eden and Tunstall 2006, Schanze et al. 2004). All three projects connected people with urban rivers. Seoul residents dip their feet into the water on hot days, Denver residents surf and swim through constructed waves, and Munich residents sunbathe and build bonfires on gravel bars. Residents from all three projects seem to value the river design and in the case of the South Platte Greenway, the project spurred numerous other cities to invest in greenway developments. All three projects lead to reinvestment in the areas surrounding the river and in the Cheonggyecheon example to Lee Myung-Bak's rise to President of South Korea. When these social factors are combined with the ecological they provide justification for the projects and measures of success, even though they may have limited ecological restoration benefits (Findlay and Taylor 2006).

Linking ideal perceptions of a river with ecologically sound designs may encourage a shift in people's understanding of the ecology within cities. The ideal form of the river in the Isar case was at *Flaucher*, where recreation dovetailed with natural river processes. The fact that people liked the appearance of the shifting gravel bars and braided channel may have been a fortunate coincidence, but it suggests there are opportunities to simultaneously improve the aquatic ecology and human conditions. Future study could investigate the relationships between aesthetic preferences, recreational use, and ecological river restoration. Some of the challenges in this study were a lack of data or similar data for comparison, different project timeframes, and information in three different languages. Acquiring the data required contacting project experts for information. Despite these limitations, this study offers insight into urban river projects with different trajectories toward more self-sustaining rivers or more energy and maintenance requirements. All three projects serve as a human amenity, providing public park space in the city, but the Isar project allowed people to find pleasure in connecting with the river while giving the river room to be dynamic. In contrast, the Cheonggyecheon is an urban "water feature," a fountain whose operation requires constant inputs of water, energy, and maintenance so that it appears clean and ever flowing.

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Table 4. Key attributes of the three urban river projects, objectives with an ecological focus are underlined and the fraction of ecological objectives calculated.

Site	**Cheonggyecheon**	**South Platte**	**Isar**
Length Restored (km)	6	16	8
Cost ($)	281,000,000	75,000,000	38,000,000
Timeframe (years)	2002-2005	1975-Today	2000-2010
City Population[1]	9,700,000	2,400,000	1,300,000
Population Density (people/km^2)	17,219	1,428	4,205
Average annual precipitation (mm)	1,370	402	954
Average maximum discharge (cms)	1.4	1,107	420
Objective #1	"To restore the cultural and historical heritage of downtown Seoul."[2]	"Reclaim South Platte in Denver (10.5 miles) environmentally and establish River as a recreationally boatable amenity."[3]	"Improving flood protection."[4]
Objective #2	"To bring back the ecosystem in the heart of the city."	"Create open space parks, and natural areas throughout River in Denver."	"Returning the river landscape to a near-natural state."
Objective #3	"To initiate a balanced development; old and new city section."	"Create concrete hike-bike-maintenance path along River in Denver."	"Restoring the ecological functions."
Objective #4	"To provide hand-on eco experience to millions of citizens."	"Connect River improvements to existing park/recreational amenities."	"Upgrading the banks of the Isar river for leisure and recreation activities for urban residents."
Objective #5	-	"Insure that each improvement continues or expands the flood carrying capacity of the River."	"Improving the water quality."
Objective #6	-	-	"Increasing the residual water volume."
Fraction of ecologically oriented objectives	2/4	2/5	4/6

[1] United National Population Department 2009
[2] Noh and Hwang 2010
[3] The Greenway Foundation 2010
[4] Zinsser 1999

Table 5. Comparative evaluation of the three urban river projects based on ecological standards for river restoration (Palmer et al. 2005). A change (Δ) of 0 indicates no change, while 1 indicates a positive change.

Criteria	**Indicator**	**Cheonggyecheon**			**South Platte**			**Isar**		
		Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ
Guiding image of dynamic state	*Design plan that is not fixed and considers watershed*	No, only 8 km of river considered and static focus	—	0	No, only 16 km of river considered	—	0	Yes, historical/ watershed analysis, guiding image	—	1
Ecosystems are improved	*Natural flow regime implemented*	Buried culverts conveys storm runoff	Water pumped from Han River and subways	0	Dam upstream, diversions, wastewater augmenting flow	Increased minimum flow (4.25 cms)	1	Dam upstream, diversions	Increased minimum flow (5-15 cms)	1
	Water quality improved	BOD mean 51.1 mg/L_2	BOD mean 3.3 mg/L	1	No data found	Decrease in nitrates and E.coli	1	No data found	Enhanced wastewater treatment (April-Sept.)	0
	Streambed and banks improved	Streambed and banks underground	Streambed exhumed	1	Simplified channel, narrowed width	Eliminated longitudinal barriers, no change in width	1	Simplified trapezoidal earthen channel	Eliminated longitudinal barriers, floodplain widened, vertical heterogeneity of bed increased	1
	Number and diversity of species	98 species: 4 fish, 5 macro-invertebrate	788 species: 27 fish, 39 macro-invertebrate	1	No data found	Decline in macro-invertebrate diversity and native fish	0	Macro-invertebrate abundance, diversity & functional group abundance recorded	Macro-invertebrate abundance, diversity & functional group abundance increased	1
Resilience increased	*Maintenance requirements*	—	Water pumping and algae removal	0	—	Park maintenance and fish stocking	0	—	River shifting its banks and floodplain reconnected	1
No lasting harm	*Little native vegetation removed or damaged*	Little vegetation to be lost	—	1	No data found	—	0	Vegetation documented and preserved	—	1
Ecological assessment completed	*Available documentation*	Data available	Data available	1	Limited data available	Data available	0	Data available	Data available	0
Ecological Success		Low Success – 5/8			Low Success – 3/8			High Success – 6/8		

Figure 25. Maps of the three projects showing the location in the country and the restoration reach with the adjacent open space along the river.

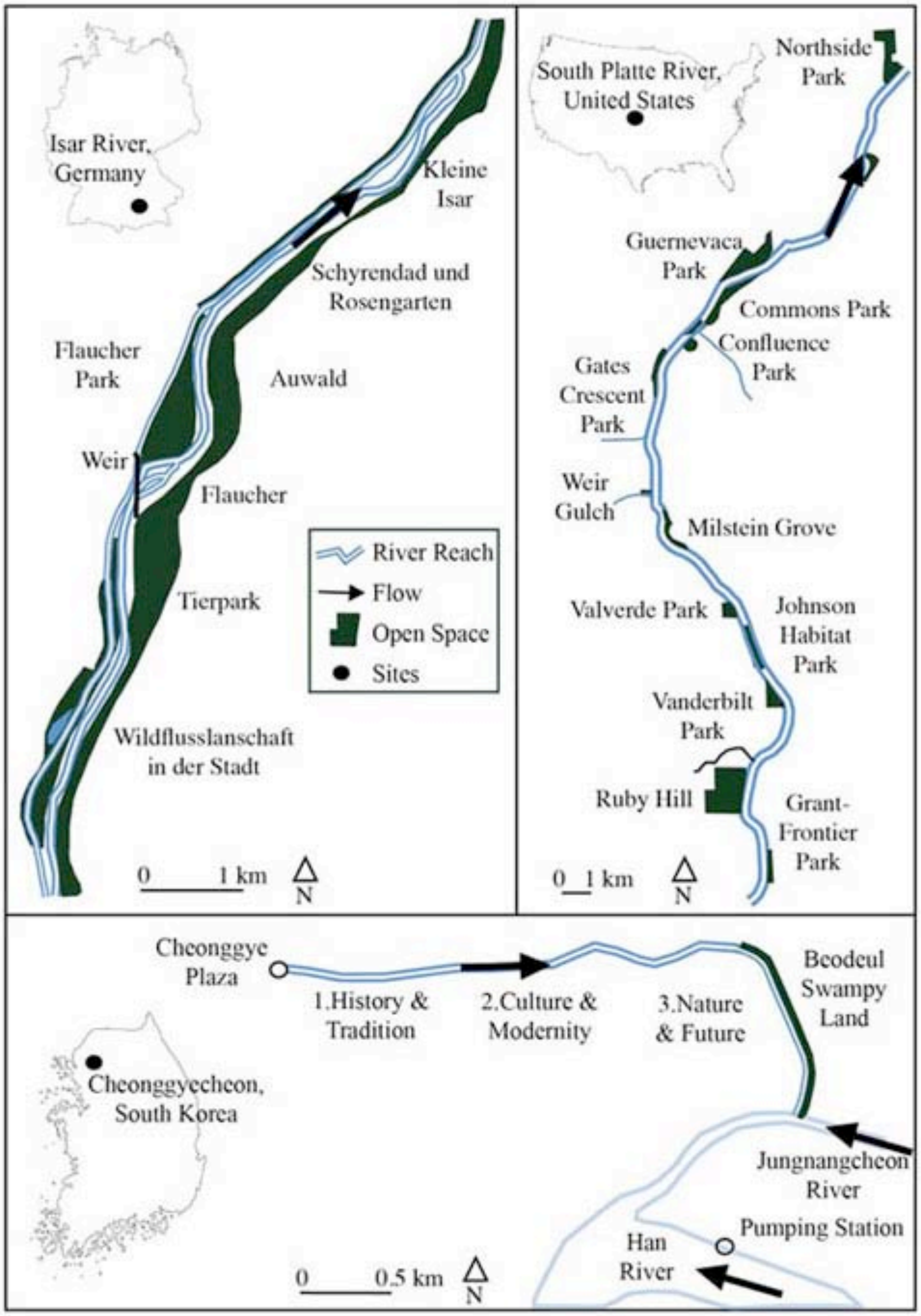
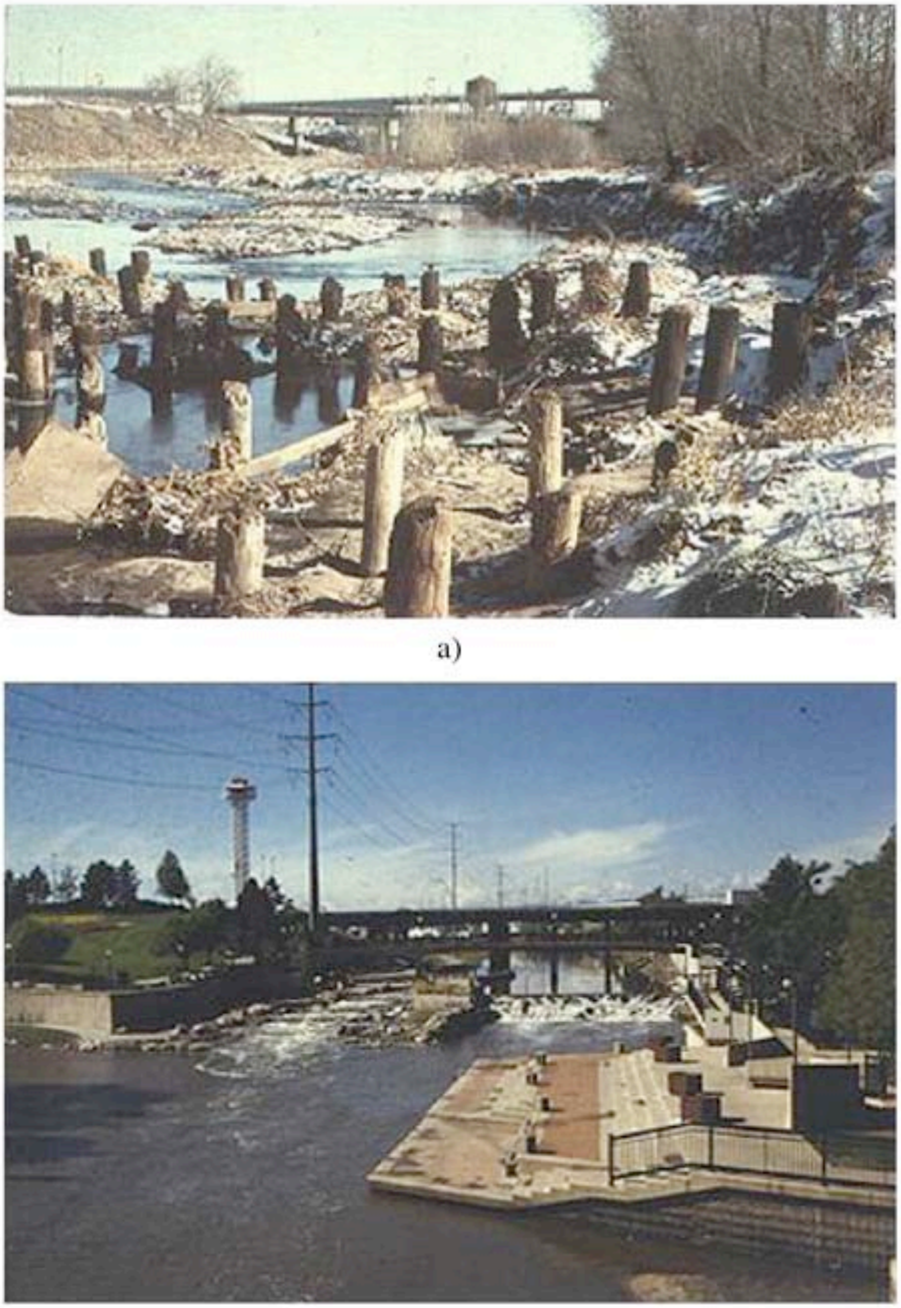


Figure 26. Before (a) and after (b) images of the Cheonggyecheon in downtown Seoul illustrate the daylighting of the creek (KBS World 2010).

a) b)

Figure 27. Workers scrub the algae off the rocks and bottom of the Cheongyyecheon (François Rejeté).

Figure 28. The South Platte River in 1974 (a) and in 1990 (b) showing the transformation and creation of Confluence Park (Greenway Foundation).



a)

b)

Figure 29. The Isar River in 2008 (a) and in 2009 (b) depicts the change in the channel pattern and gravel banks after rehabilitation (Wasserwirtschaftsamt München).

a)

b)

Figure 30. Honeycomb rock ramps on the Isar River as seen from above (2011 Google -Imagery, ©2011 AeroWest).

Chapter 5

Artificial Whitewater Designs: The impact of Olympic courses and a new paddling discipline

Abstract

Despite the fact that more than one hundred artificial whitewater designs exist today, seven of which are Olympic venues, there is little known about the history of these designs. Goodman and Parr completed the only historical assessment of artificial whitewater in 1994, before the 2000 Olympics lead to a recirculating whitewater course with no connection to a stream and during a time when a new discipline of paddling called freestyle emerged. The 2000 Olympic recirculating course is self-contained, hydraulic pumps circulate the filtered water, and the paddler stays in their boat and rides a conveyor belt from the bottom to the top of the whitewater. This study traces the evolution of whitewater designs through an inventory of sites, 28 qualitative interviews with designers, coaches, and athletes, and comparison of the difficulty of 55 of the whitewater designs using a quantitative index based on the design dimensions. The results show a trend towards greater control over the hydrology to create a fair playing field for competition and to make whitewater more reliable, safe, and convenient. Olympic courses and the addition of a new paddling discipline, freestyle, brought about key transitions in artificial whitewater design. The most significant transition being a move away from streams where the sport began and from the wilderness ideal that defined early outdoor sports. This study adds to the literature on constructed environments for outdoor sports where the experience is distilled and the undesirable aspects of the outdoors removed.

5.1 Introduction

In 1906, Hans Klepper made the first commercially manufactured whitewater kayak in Germany. Since then, whitewater paddling has been a popular outdoor recreation activity in Europe, Britain, and the United States (USA). Sue Taft described the history of whitewater paddling in the USA, dating back to 1916 when the Appalachian Mountain Club organized excursions and published trip reports in the journal *Appalachia* (Taft 2001). The club is the oldest conservation organization in the nation and encourages people to get outside to enjoy the outdoors as a basis for successful conservation and stewardship. Early whitewater paddlers were downhill skiers who wanted to ski in the mountains during the winter and paddle mountain streams in the summer (Taft 2001). The thrill of gliding down a mountain on skis was similar to the sensation of maneuvering a kayak through whitewater rapids. The rivers that these whitewater paddlers explored were an important attraction, in part because they lacked design and provided a wilderness experience, fitting the wilderness ideal at the time.

It was only a matter of time until whitewater paddlers organized competitive races in the summer in the same way they held downhill ski slalom races in the winter. Canoe slalom racing began in 1933 on the Aar River in Switzerland where paddlers navigated around buoys down a 500 m long course. The Austrians were the first to suspend pairs of poles over the river, called gates, instead of using buoys. These slalom courses sometimes contained a set of yellow poles in a line perpendicular to the flow called a barrier that was meant to represent a fallen tree, a dangerous obstacle encountered on rivers (Endicott 2007). Today, slalom kayaking follows the Austrian tradition with paddlers navigating their craft through gates suspended over rapids, going downstream through some gates and upstream through others in a pattern of movement that mimics running a river. In ski slalom racing the skier goes only downhill through the gates, but in a river the water flows upstream in an eddy, hence the upstream gates.

Canoe slalom debuted as a demonstration event in the Olympic games in Munich, Germany in 1972 and lead to some of the earliest artificial whitewater designs. Two courses quickly developed in preparation for the Games and countries with canoe slalom teams built artificial slalom training courses through the 1970-1990s. Canoe slalom returned to the Olympics in the 1992 Barcelona, Spain games and both this course and the 1996 course for the Atlanta, USA Olympics were whitewater enhancements to streams. The 1996 course generated controversy because of the extent of alteration of the streambed to make a more difficult course. In 2000, the Sydney, Australia Olympics lead to the first recirculating pumped whitewater design with no connection to a stream. The emergence of artificial whitewater for slalom racing was not the only impetus for artificial whitewater. Some of the first whitewater designs were boatchutes to provide safe passage around dams. Additionally, in the 1990s freestyle kayaking, a discipline focused on surfing, developed and resulted in construction of numerous whitewater parks in the USA. Following the 2000 Olympics, recirculating courses were built as competition sites and as commercial venues not associated with an Olympic event.

Today, more than one hundred artificial whitewater designs exist in twenty-three countries around the world, yet there is little known about the history of these designs (Table 6). Goodman and Parr completed the only historical assessment of 12 artificial whitewater designs in 1994, before the development of a recirculating course for the 2000 Olympics and before freestyle kayaking grew in popularity (Goodman and Parr 1994). They developed a quantitative measure of the whitewater difficulty, called the power surface index (Ψ = (discharge x head x 10^4)/(length x mean width) to compare the courses. This study traces the evolution of whitewater designs and reveals how Olympic whitewater courses and the emergence of freestyle paddling brought about key transitions. Through an inventory of whitewater designs, qualitative interviews with twenty-eight experts including designers and planners, competitors, and coaches, and comparison of the whitewater difficulty for 55 designs with available information (Figure 31), a clear trend emerged of greater control over the hydrology to create a fair playing field for competition and to make whitewater more reliable, safer, and convenient. The transition from paddling on whitewater streams to paddling on courses with no connection to a stream has implications for the whitewater experience and potentially conservation and preservation of wilderness.

5.2 Whitewater debuts in the 1972 Olympic Games

The 1972 Olympic demonstration slalom event spurred the creation of three of the earliest artificial whitewater sites in 1971 in preparation for the games: Eiskanal (Augsburg, Germany), Zwikau (Zwikau, Germany), and Kernville Riverside Park (California, USA). Architects R. Borckel and E.K. Müller and Landscape Architect Gottfried Hansjakob designed the Augsburg Olympic slalom course in a concrete flow diversion canal used to divert drift ice away from turbines on the Lech River. The channel is called the Ice Channel or Eiskanal in German. The course cost approximately $1.6 million and mimicked the mountain streams where the sport developed, but had a distinctive sculptural style (Figure 32).

"The course was a crude but effective facsimile of the high mountain streams on which this rugged sport had grown to popularity. Channelized, serpentine, and beset at intervals with thirty-two concrete rocks, that together with a current that reached 6 m/s, generated tumultuous whitewater conditions, the course was a formidable challenge to even the ablest canoeists." (Gordon 1983)

The course follows an approximately 2,000 m winding cement channel flanked with terraced grass lawns where ~25,000 spectators gathered on both sides of the channel for the event (Figure 33). A hydro-engineering consultant constructed a 22 m physical model of the course before construction began to test the whitewater design (Sport Munchen 1972). Since 1994, the course has been open to paying guests 280 days per year and still hosts major slalom competitions (Regio Augsburg Tourismus 2011).

Fearful that the West Germans would have too great of an advantage in the Olympic slalom races with the new Eiskanal, the East Germans and the Americans quickly constructed enhanced instream slalom courses the same year, 1971. The East Germans made a slightly shorter copy of the Eiskanal in Zwickau on the Mulde River by constricting the width of the river in places. The East Germans went on to win all of the Gold Medals in whitewater canoe-kayak at the 1972 games, a feat that has never been copied at an Olympic Games or World Championship whitewater paddling event. In the USA, a stretch of the Kern River in California, Kernville Riverside Park, became a training site for the Olympics and the site of the USA team trails. Tom Johnson, then USA Olympic Team coach, added large boulders in long rows extending perpendicular to the flow to narrow the channel width and create bigger and more difficult rapids. There was no design evaluation, drawings, or analysis by engineers, but the District Engineer with the Army Corps of Engineers agreed to the proposal (American Canoeist 1972). The project involved bank restoration in addition to the whitewater enhancements. Bulldozers could only access one side of the river, so to add rocks to the other streambank, a dump truck backed up to the top of the riverbank and let boulders roll down the bank into the water. Those that did not roll far enough were moved into place by those attending the Kernville Whitewater Training Camp (Figure 34)(American Canoeist 1972). Because the boulders were not set permanently to the stream bottom, they have moved, and today there is a renovation project currently underway to create more permanent grouted drop structures in the river park (Kern River Newsletter 2011).

5.3 Modifying existing water infrastructure

The first record of a whitewater design built in 1965 is in a park in Vichy, France where a diversion channel became a whitewater canoeing course. Goodman and Parr describe it as "an afterthought during the construction phase of a sports complex" and a "good way of using a tail-water from a small ornamental canal" (Goodman and Parr 1994). There was no additional information available on the purpose of this site, the designers, or its history. However, the idea of modifying existing water infrastructure to include whitewater as a way to provide boat passage around a dam, create a slalom training site, or provide a place where people can access the river for recreation has justified artificial whitewater designs. Most of the boatchutes in Europe are slalom training courses and competition sites, while in the USA they were either slalom courses or public parks.

Three years after construction of the Kernville Riverside Park, engineer Richard McLaughlin working with McLaughlin Water Engineers designed the Confluence Boatchute (1974), now called Confluence Park, as a whitewater passage around a dam on the South Platte River in Denver, Colorado. The design includes a steep series of small drops spanning the bypass channel to form waves. The drops are made from a mixture of concrete and rock and the grout is at the surface of the drop to ensure it is smooth and does not form a hazard. For example, a crack in the grouted rock on the bottom of the channel could trap a swimmer's foot and pin them to the bottom in an unsafe position. Even though the gradient of the boatchute is steep (2%), the site is used extensively by novice paddlers and children swimming and floating in inner tubes (Figure 35). At high flows, the public park has a clean safety record with no fatalities reported in its thirty-seven year history and no special maintenance funding. The objective of the park, according to one of the designers is to "not only improve the streambed for whitewater boating, but to re-integrate river corridors into communities."

One of the earliest conceptions of a whitewater park was the Holme Pierrepont National Watersports Center near Nottingham, United Kingdom (UK). Engineer Frank Goodman began working on the design in 1970 but construction was delayed until 1985 due to the novelty of the design at the time. The impetus for the center was to provide a boat passage around a dam and to improve river access, which in the UK is an issue because private ownership of the riverbank extends to the riverbed and there is only unlimited access to a select number of river (Personal communication Frank Goodman 2010). The whitewater was part of a larger park where extensive gravel pits were made into a lake for flatwater paddling, rowing, water skiing, and fishing. Joint funding for the project (2.2 million pounds in 1986) came from the Nottinghamshire County Council and the National Water Sports Center. The original purpose as envisioned by the designer was not "to make an Olympic slalom course, but to get people into the sport" (Personal communication Frank Goodman 2010). However, when Holme Pierrepont opened, the country's slalom governing body, the British Canoe Union, bought access to the course during the weekends for the first eighteen months the course was open. This shifted the purpose of the site towards competitive training and away from the general recreational paddler. This balance evened out after the first year; Goodman and Parr reported that there are bigger returns on the investment from individual users than organized competitions and private bookings (Goodman and Parr 1994).

5.4 Slalom training courses

Following the 1972 Olympics, slalom courses were built in bypass channels on streams mainly in Europe and the USA from the 1970s until 2000 to provide training and competition sites. However, whitewater slalom was not in the Olympics again for 20 years, mainly due to the cost of building artificial whitewater (Personal communication Shipley and Endicott 2010). Additional courses were built after 2000, notably Ivrea in Italy in 2007, but the majority were built before the 2000 Sydney Olympics when the first recirculating course was constructed. Three of these slalom-training sites in Europe (Tacen, Trnavka, and Bourg) have some of the most difficult whitewater of any designs, due in large part to their steep slopes. These sites took advantage of existing water infrastructure, mainly dams and diversion channels, and a major goal was to control the flow of the water in the course using a weir at the upstream end. Variable flow levels during a race would not provide a fair playing field for competition.

Three courses in the USA, the Wausau Slalom Course (1976) in Wisconsin, the East Race Waterway (1984) in Indiana, and Dickerson Whitewater Course (1991) in Maryland are examples of slalom training courses built into preexisting water infrastructure. The Wausau course is a bypass channel around a dam, the East Race Waterway was built in a millrace, and Dickerson is in a concrete channel that conveys cooling river water from a coal fired power plant (CDWR 2009). The courses require an entry fee, have limited hours, are supervised, and streamflow is controlled with adjustable flap gates at the top of the course or in the case of Dickerson by the cooling rate. The Dickerson course is unique because the water in the course is up to 35 degrees Fahrenheit warmer than the Potomac River water and athletes can train in the winter when the nearby river is frozen (Figure 36). Architect John Anderson and slalom paddler Scott Wilkinson designed the Dickerson course in a pre-existing 275 m long, twelve meter wide concrete trapezoidal channel that became a slalom whitewater course with the addition of cement gumdrop shaped structures, wing dams, and submerged features to constrict the flow and make whitewater. The course was inexpensive costing only $250,000 (Taft 2001) and was meant to be similar to the 1992 Olympic course to improve the USA athletes training in preparation for the Olympics the following year.

The first whitewater course built in England, Cardington Artificial Slalom Course built in 1982, is a slalom course in a concrete bypass channel. The permanent fiberglass obstacles added to the channel, called hippos and dollies were a precursor to the concrete gumdrop obstacles in the Dickerson course. The course is multi-purpose serving as both a whitewater slalom course and a flood control structure. At the top of the course is an automatically controlled sluice gate that controls the water flow in the channel. In contrast, the first artificial whitewater course in Slovakia, The Ondre Cibák Water Slalom Complex in Liptovsky Mikulas (1978), does not have a controlled water flow but fluctuates with the level of the Vah River. The course is open from April to October when the water flow is suitable, and is the best in May and June when the water flow is high. There is a starting pool at the top of the two diversion channels designed by Ondre Cibák. One channel called the Vah, is easier while the other, Orava, contains more difficult whitewater designed for slalom training (Cubanova and Rumann 2009). The edges of the channel have round rocks, which provide the aesthetics of a mountain stream. In the middle of the Vah, course the Orava flows in and merges into one channel. Permanent wing deflectors made of rock and cement that extend part way into the channel at a perpendicular angle to the main water flow form the whitewater. It was the first design to contain two separate channels that reconnected.

5.5 1992 and 1996 Olympic Games in streams

Canoe slalom returned to the Olympics in 1992 and has been an event in every subsequent games. The 1992 Olympic slalom race was held in a bypass channel called the *Parc Olímpic del Segre* on the River Segre in La Seu d'Urgell, a mountain city in the Pyrenean region of Spain. Ondre Cibák, the designer of Liptovsky Mikulas, designed the course and the total cost including construction was $10 million (COOB 1992). At the top of the course the channel splits into two: a beginner channel and competition channel that converge together after 130 m a feature Cibák used in the Liptovsky Mikulas course. The flow in the beginner channel is 3-10 cubic meters per second (cms) and the slope is more gradual making the whitewater less difficult than in the competition channel. This design allows for a range of paddling abilities to use the course post Olympic games and was a feature copied in subsequent courses. A unique aspect of the design was a reversible hydroelectric station that could add 12 cms to the flow through the course when the streamflow was low. Alternatively, when the streamflow exceeded 17.5 cms the station could run in the reverse direction and generate four million kilo watt-hours of electricity per year (McLaughlin Water Engineers 1999). The course was shorter than the 1972 Eiskanal and the number of gates dropped from thirty to twenty-five for enhanced shorter television coverage (Personal communication Bill Endicott 2011).

Four years later, the United States Forest Service (USFS) constructed the Ocoee National Whitewater Center for the 1996 Olympics. It is the most intensive manipulation of a streambed into a slalom course at a construction cost of $7.7 million. The Olympic host city of Atlanta worried about the cost of constructing whitewater, so the USA coaches were asked to "find a venue that someone else was willing to pay for" (Personal communication Richard McLaughlin 2011). The Tennessee Valley Authority (TVA) de-watered a reach of the Ocoee River in Tennessee in 1942 for power generation and the coaches and Olympic representatives identified this as the site for the slalom course, even though it was far away (40 km) from the Olympic village (Atlantic Committee for the Olympic Games 1997). Supplying water to the dewatered reach where the slalom competition would be held meant a loss in hydropower generation. During water release tests, it was determined that 85 cms of water would be needed to provide a difficult course with the existing conditions. However, if the channel cross-section was narrowed significantly only 45 cms of water would be required, an amount the TVA could supply reliably (Gromer and Herbst 1996).

The designers of the Ocoee course Richard McLaughin and John Anderson added 60,000 tons of rock and cemented it to the stream bottom to narrow the channel by one-third to one-half and form more challenging whitewater (Gromer and Herbst 1996). By decreasing the cross-sectional area of the channel, the designers sped up the water velocity and increased the difficulty of the whitewater. The USFS constructed levees of limestone topped with local boulders 6-15 m inside of the riverbanks (Figure 37). They filled the space between the riverbank and levee with individually fitted sandstone rocks imported from nearby government land, and built artificial rocks with steel reinforced concrete that was sculpted and colored to match surrounding rocks (American Whitewater 1995). Before the narrowing of the channel and addition of the rock and cement, the river reach "lacked the punch of a world class race course." The designers made a ninety-one meter, 1:10 scale physical model because there was little opportunity to change the design once it was built. Controversy surrounding the design and streambed modification because some viewed it as "another insult in a long list of man made intrusions in the area" (American Whitewater 1995). After the Olympics, the reach is again dewatered for two-thirds of the year excepting Fridays and weekend days with scheduled water releases for paddling (TVA 2010).

5.6 Freestyle and whitewater parks in the USA

Freestyle canoe and kayak became as a new discipline of whitewater paddling in the 1990s. The discipline was originally called rodeo kayaking because of the similarity of dropping into a large hydraulic and trying to stay in control and the sport of riding a bronco horse. In freestyle the paddler surfs in one place on a wave or in a hydraulic called a hole and performs maneuvers such as spins, cartwheels, and front flips. It is not currently an Olympic event, but the popularity of the discipline lead to new types of whitewater features, namely surf waves and holes built primarily in public parks in the USA. These parks are alternatively called whitewater parks, boater parks, and park-and-play spots.

The USA has the greatest number of whitewater designs with 51, half of these are freestyle focused parks located in Colorado (Table 6). Most cities construct whitewater opportunistically when a safety hazard in the river needs to be removed or modified, usually an aging dam or weir (Turner-Peterman Consulting 2009). The popularity of the parks spread first around Colorado and then through the rest of the nation as evidence of their positive economic impact to their host cities grew (Boyd 2003, Sorvig 2009). Surfing freestyle waves were added into Olympic courses and slalom courses. The managers of the Wausau course, for example, modified the whitewater in the 1990s to create freestyle waves and attract more paddlers. Whitewater parks have a lower difficulty of whitewater probably because they are designed to be safe for the public (Figure 31). All of the parks, except one, are open to the public at no cost, and there are no staff or lifeguards operating the parks. They are popular places for many water activities: swimming, wading, tubing, and others.

The desire for greater control over the conditions in whitewater parks lead to efforts to secure water rights for recreation and whitewater features that were adjustable to variable streamflow levels to maximize the functionality of the designs. Colorado is not only home to most whitewater parks it is the only state with recreational in channel diversion (RICD) water rights for guaranteed water flows in the whitewater parks (Hagenstad et al. 2000, Raucher et al. 2000). The first RICD was in 1986 for a boatchute on the Cache La Poudre River in the city of Fort Collins. The right specified 1.6 cms a small amount of water in the river and in 1992, the city was granted 0.8 cms by the Colorado Supreme Court (Young 2006). In the next eight years, five other cities in Colorado applied for RICDs and the Senate Bill was amended to limit the water rights (City of Golden 1998, Eagle River Water and Sanitation District Application 2002, Town of Breckenridge 2002). The tipping point identified by park designers and regulators started when the city of Golden applied for an RICD of 28 cms in its whitewater park, essentially a large portion of the flow in Clear Creek. The whitewater designers testified that the higher flow level in the park attracted paddlers since the whitewater features are optimal at 28 cms (Personal communication Richard McLaughlin and Scott Shipley).

Adjustable whitewater features increased the reliability and suitability of the waves and holes to different streamflow levels and paddler abilities. In 2009, Jason Carey with the firm River Restoration.org installed computer-controlled air bladders in the bottom and sides of an artificial wave in the town of Vail, Colorado's existing whitewater park. The computer system automatically reads the streamflow and adjusts the amount of air in bladders to form an optimal wave at different water levels. An override system deflates the bladders during floods. The $376,000 enhancements were a response to criticism from professional freestyle paddlers that the wave was too small to do any scoring freestyle maneuvers during the Teva Mountain Games competition, which draws 33,000 spectators (Figure 38, Town of Vail 2007). According to the project manager, the air bladders are "the equivalent of what snowmaking has done for skiing"; it makes the wave functional despite low flows at the end of the summer.

In the past twenty years, as regulatory review of instream whitewater designs in the USA increased there was a mandate to consider habitat impacts. The floodplain impacts, fish passage, and permanency of the designs are all mandatory considerations that resulted in more sophisticated two-dimensional modeling to predict fish passage. At the Placer County Water Agency (PCWA) Facility (Figure 39) on the American River in California designed by McLaughlin Water Engineers there are two adjacent channels, one with underwater screens for a water diversion and the other with the whitewater waves. Both channels have sloped walls and boulders along the edges to create interstitial space and facilitate upstream fish passage. The channels also allow sediment to pass through, a feature not possible in a conventional dam (Personal communication Richard McLaughlin 2011). While regulations tightened and environmental considerations became a required element of whitewater parks in the USA, another big change in whitewater occurred in the 2000 Olympics.

5.7 2000 Olympic games disconnects from streams

The Penrith Whitewater Stadium built for the 2000 Olympics in Sydney, Australia was the first recirculating whitewater stadium with no connection to a stream. The Penrith Whitewater Stadium set a precedent for all subsequent Olympic designs, which have all been recirculating courses with various shapes (Figure 40). It is a concrete channel following a u-shape with moveable whitewater obstacles and hydraulic pumps to circulate the water. The original u-shape, much like a running track allows for spectator viewing of the entire racecourse. Slalom kayaking was almost not included in the 2000 Olympics because the host city never put slalom in the bid. The International Olympic Committee dropped the event because they thought it was not worth the investment in a place with no tradition of whitewater paddling and few whitewater rivers, specifically no whitewater rivers near the host city, Sydney. In response, John Felton, the International Canoe Federation (ICF) technical representative led the successful lobby to readmit slalom to the Olympic program (Personal communication Bob Campbell 2011). Felton was supported by Frances President Jacques Chirac and the former German Prime Minister Helmut Kohl (Clarey 2000). The initial estimate for the course was twelve million Australian ($16 million at the time), too expensive to keep the event in the games, but the cost was cut in half by an innovative funding deal that provided the city of Penrith with management and operation of the course following the games in exchange for financial contribution (Sydney Organizing Committee 2001). Financial support also came from the countries with slalom racers (Clarey 2000).

The Sydney Olympic Co-Ordination Authority appointed Pacific Power International (PPI) to undertake the detailed design, project management, and construction of the entire venue. Peter Heeley, the project director with PPI, worked with John Felton and Richard Fox (ICF) and Whitewater Parks International on the concept and design development of the whitewater channel. PPI appointed architect Gross Bradley to design the spectator amenities, administration, and boat storage building. Lorna Harrison provided landscape consultation and Hydrostadium supplied the moveable obstacles (Personal communication Bob Campbell 2011). The course made a profit in its first year of operation, and the financial model of funding from the host city has been used in the majority of recirculating whitewater stadiums built since Penrith. According to the designer of the course, it “leant itself to imagining how much more could be done to make a commercial venue serving many different uses” while creating a tourist attraction.

Over time the difficulty of the whitewater in the Olympic courses increased, fitting the Olympic motto faster, higher, stronger. In Athens, Greece, the Helleniko Whitewater Stadium built for the 2004 Olympics looped back on itself in a figure eight via a bridge designed by architect Nikos Fintikakis, with consultation from HydroStadium. The course uses saltwater because of Greece’s lack of freshwater and the high evaporation rate in the Mediterranean climate, but the unexpected result was quick corrosion of the cement, continued maintenance requirements, and the saltwater made it difficult for competitors to see when it splashed into their eyes (Macur 2004). The climax in increasingly difficult Olympic courses was the 2008 Beijing Shunyi Rowing-Canoeing Park, which had a maximum water velocity of roughly eight meters per second (Beijing Organizing Committee 2008). The designers (HydroStadium) built a U-shaped course with vertical and slanted walls to provide close spectator access and reduce the surging effect caused by vertical walls. There are two additional channels used for warming up and down.

The recently completed 2012 London Olympic Lee Valley Whitewater Center breaks the trend of more challenging recirculating Olympic whitewater courses over time.[2] Unlike the high

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[2] The index is a general indication of the whitewater difficulty, but it does not take into account the width and channel cross section variations, the fact that obstacles can be moved into different alignments to change the width, o the shifting water velocity in a particular location in the

pumping rates and head of the Helleniko and Shunyi courses, the Lee Valley pumps at about the same rate and head as the Penrith course. Whitewater Parks International designed the course and during the process studied the performance characteristics of former Olympic recirculating courses to determine appropriate technical parameters. They found that the Helleniko course had hydraulic variation and inconsistency in the surging, a factor in the Shunyi course as well. The goal in the Lee Valley design was to make a more challenging course than Penrith, but "without the undesirable hydraulic effects that make for uneven competitions" and to make a course with a regional legacy. The design accomplished their goal of a regional legacy in a second, independent training channel with a separate set of pumps, a lower pumping requirement, and one-fifth the cost of the Olympic channel to operate. This opens up the course for continued use after the games. The two-channel design met the objectives of a sustainable business plan. The cost to construct the channel was $49 million (the construction cost was a fixed bid by the contractor at $30 million) and it was the first Olympic venue to be completed for the London games this coming summer.

5.8 Non-Olympic recirculating courses

Since the Penrith 2000 Olympic course, nine recirculating whitewater courses have been built for commercial recreation and international level slalom and freestyle competitions but were not associated with an Olympic games. Chronologically, the commercial recirculating courses were constructed in: France (Cergy), China (Nanjing), USA (USNWC), Germany (Kaunpark Marlkeeberg), Netherlands (Dutch Water Dreams), USA (ASCI), Spain (Zaragoza), Wales (Cardiff), and China (Rizhao). The difficulty of the whitewater in these re-circulating courses is less than the Beijing Olympic course but higher than whitewater parks (Figure 31). According to van Bottenburg and Salome, in commercial terms the use of the courses as training centers for Olympic athletes is subordinate to consumer entertainment (van Bottenburg and Salome 2010). It is economically more advantageous to run commercial rafts down the courses, and competitions do not generate nearly as much money so the training time is limited.

The recirculating courses all have filters and water treatment since they are essentially a large pool. They have additional sporting venues built near the courses along with food vendors and in some cases conference halls. They all have similar whitewater design characteristics with adjustable obstacles, cement channel bottoms, conveyor belts to transport the paddlers back to the start of the course without exiting their boats, and large hydraulic pumps to circulate the water. None of the courses has trees close to the edge of the water because a tree or limb in the course would be a hazard, as it is for paddlers in a river. Some of the courses are pre-ticketed so the managers know when it is economical to turn on the water, and there are lifeguards and cameras on the courses for safety.

The Cergy Neuville recirculating course outside of Paris, France was built soon after the Penrith Olympic course in 2000. The course objective was to offer, "a general public leisure activities in the spirit of developing open-air sports in an urban area" (Hydrostadium 2011). A pumping station with four pumps drawing a maximum of 15 cms from a lake provides the water

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course. I use the index as an assessment tool to compare the whitewater designs through time and it does not capture the difficulty of individual rapids in the design.

flow. The course is located on the inside of a river bend of the Oise River where industrial gravel pits were dug in the past, creating the current lakes. The water flow can be adjusted to fit a beginner paddlers needs or be used as a training site for Olympic slalom racers at a higher water flow. The course is in a large sports center and recreational park spanning 250 hectares with additional lakes used for sailing, windsurfing, and a water ski tow. The advertising for the course states "the sensations are similar to those experienced on wild mountain rivers, but only thirty minutes from Paris" (Xtrem Adventure 2010). This marketing of the experience is echoed in Dutch Water Dreams recirculating course in the Netherlands where they call the course "an adventurous experience" and a way to "Go with the flow" (van Bottenburg and Salome 2010).

The U.S. National Whitewater Center (USNWC) built in 2006 in Charlotte, North Carolina has two channels: one meant for beginners and the other called the competition channel meant for more advanced paddlers, similar to the 1992 Seu d'Urgell course and the Lee Valley Whitewater Center. The water flow into the two channels at the USNWC is controlled with a plate system and either channel can be independently shut off, but there is only one set of pumps for both courses. The center cost $37 million to construct with a target of $11 million annual revenue and $4 million in operating revenue based on 300,000 annual visitors. The seven hydraulic pumps can circulate 35 cms and the water is tap water cleaned with a $1 million ultraviolet-light filtering system (Willoughby 2006). One pump requires roughly $45 per hour to run. The course is designed to host "hundreds of thousands of commercial rafters per year often hosting more than 2,000 rafters in a single day" (Shipley et al. 2010).

Recirculating courses represent the complete control over all aspects of the whitewater for specific functions. In designing the USNWC, engineer Scott Shipley with S2O Design and Engineering interviewed canoeing instructors to learn how the whitewater could be tailored for teaching beginners in the recreational channel. The result was the first drop has a jet of water with a large eddy downstream on the river left, followed by another jet with an eddy on the right. This sets up ideal conditions for learning how to enter and exit the main flow of the current. Another consideration was making a wave where instructors could help students learn to surf. Shipley designed a wave in the beginner channel so an instructor can wade out, hold the bow of the student's kayak, and stabilize them in the wave as they take their first surfs. He worked with professional paddler Anna Levesque to identify women-specific needs such as a private place where women could practice their surfing skills without feeling they were being watched by their male counterparts or spectators, and a place where they could gather (Personal communication Scott Shipley 2010).

Another commercial recirculating course in the USA, Adventure Sports Center International (ASCI) was built one year after the USNWC on a mountaintop in Maryland adjacent to a ski resort. Richard McLaughlin, the designer of the Confluence Boatchute and 1996 Ocoee Olympic Course and John Anderson designed the whitewater with real-time adjustable drops, unlike other courses where the obstacles can only be moved when the water is not flowing. These features on the bottom of the channel are metal plates with air bladders underneath, called waveshapers. They are computer controlled and adjusting them can transform the channel from a pool-drop type whitewater preferred by freestyle paddlers to a more continuous whitewater rapid typical of slalom courses, thus meeting the needs of both disciplines. The waveshapers allow the course to function as "more than one type of river in one channel" (Personal communication Richard McLaughlin 2010). In the morning, the operator can run low flows and reduce the minimum age requirement to enter the course, in the afternoon they can ramp up the flow and amplitude of the whitewater features. The course cost $12 million and the campus $25 million and was funded by the Appalachian Development Plan passed by the US Congress in 1965 (Maryland Department of Planning 2008). ASCI has a unique aesthetic with large boulders along the edges of the channel to mimic the appearance of a whitewater river and to provide places for self-rescue, where a swimmer can pull out of the water on a rock. None of the other recirculating courses attempted to mimic the aesthetics of a streambank edge.

5.9 Conclusion

In the past forty years, whitewater designs transformed significantly, due in large part to the Olympic whitewater course designs. From the 1972 Eiskanal course in a bypass channel with permanent concrete structure to the emergence of the Penrith recirculating course in 2000 where the entire channel and water flow are artificial and the obstacles adjustable represents an increase in hydrologic control to make a fair playing field for competition. Artificial whitewater courses support geographer Karl Raitz's idea that as sports are commercialized the places where they occur become theaters for spectator entertainment. Raitz predicted that future sports places of the 21st century would "resemble artificial amusement park caricatures [rather] than organic places that were the product of local customs and conditions" (Raitz 1995). Geographer John Bale similarly said that the sportscape 'exemplifies a fixation with improving on nature and artificialising the landscape in its quest for the optimal sporting environment' (Bale 1999). Recirculating courses are more expensive to build and maintain, and they resemble amusement park water rides except that riding an inner tube as one would in a water amusement park is not allowed, instead it is rafting and kayaking. The earliest whitewater designs mimicked a whitewater river, but the designs became more complex over time and almost fanciful as in the figure eight course built for the 2004 Athens Olympics.

The Olympic whitewater courses were not the only factor influencing design trends, whitewater parks played an important role in the history. In the 1990s, the popularity of freestyle paddling and surfing resulted in whitewater parks throughout Colorado. Freestyle features became more adjustable and efforts to establish recreational flow provisions were all attempts to maximize the functionality of the constructed whitewater features. Over time, environmental review of the whitewater designs in streams forced more complex modeling and integration of fish passage into the whitewater drop structures. At the same time the recirculating courses incorporated freestyle whitewater features or became adjustable so that they could be both a slalom course and freestyle wave in the same channel.

Whitewater designs exemplify the control and simplification of the river environment but retain the most basic element, the whitewater. Artificial whitewater distills the pleasurable thrill of running whitewater while removing most of the un-pleasurable elements that characterize whitewater paddling on streams. These undesirable elements like shuttling a car from the top of the run to the take-out are removed in recirculating courses where conveyor belts transport the paddler in their boat to the top of the course. In whitewater parks, there is no shuttle because the paddler is staying at a single wave feature or a short stretch of the river to surf. Paddlers do not need to wait for the right streamflow conditions or season, they need to know when the pumps turn on or when the recreational water releases occur. The whitewater can be optimized to be more or less difficult, pool-drop or continuous rapids, and individual waves can change shape to create the ideal conditions for individual users with the push of a button. Paddlers are not worried about water quality in a recirculating course because the water in the course is filtered and treated. A dangerous obstacle such as a fallen tree in the river or a foot-entrapments on the stream bottom are non-existent in recirculating courses and reduced in instream whitewater parks. The whitewater designs are also closer to most people's homes in the city, making whitewater paddling and many other river activities more convenient. None of the courses is danger free but many of the risks inherent in whitewater paddling are reduced and there is an extra safety margin of being close to other people, having lifeguards, or when the course is monitored via video.

Whitewater designs represent a paradox; they are meant to be mimic of whitewater streams yet today they are completely disconnected from them. Further, the wilderness ideal that attracted early paddlers to explore mountain stream is giving way to a blended urban-constructed wild ideal where artificial designs are the norm and the social experience becomes more important than a connection with nature. It seems the whitewater itself is the priority in the designs, not the larger river setting. The personal experience of excitement and loss of balance in whitewater may be more important than the connection with a river. On the one hand, whitewater designs may be accessible to more people leading to protection of rivers and reduced conflicts over wilderness rivers. On the other hand, there are questions about the sustainability of designed whitewater, which requires massive amounts of energy and may not lead to a new generation of river conservationists or paddlers equipped to deal with dynamic river conditions. Keeping whitewater slalom in the Olympics is a struggle because of the cost of constructing artificial whitewater. The future of whitewater designs will likely follow past trends with greater manipulation and control over the hydrology to distill the whitewater experience in parks and commercial courses, Olympic designs will continue to set the design precedent, and new paddling disciplines will lead to novel whitewater features.

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Table 6. Worldwide inventory of the one hundred twenty seven whitewater sites with the closest city/state in parenthesis and the name of the stream.

Australia (3): Sams Lyons Course (Dee, Tasmania) – Brady's Lake, GoulburN River (Eildon, Victoria) – Gouldbur, River, Penrith Whitewater Stadium (Penrith, New South Wales) – no stream **Austria (1):** Terminator (Graz, Styria) – Mur River **Belarus (1):** Minsk (Minsk) – Zaslauskaje Lake **Brazil (1):** Itaipu Slalom Course (Foz do Iguaçu, Paraná) –Parana River **Canada (4):** Calgary Weir (Calgary, Alberta) – Bow River, Minden (Minden Hills, Ontario) – Gull River, Pumphouse Tailrace (Ottawa, Ontario) – Ottawa River, Rutherford Creek (Pemberton, British Columbia) – Rutherford Creek **China (7):** Mi Yi Slalom Course (Si Chuan province) – Anning River, Nanjing Whitewater Stadium (Nanjing, Jiangsu province)– no stream water source Xuanwuhu Lake, Ping Ding Shan Slalom course (Nan Province) – no stream, Rizhao Slalom Course – Rizhao Harbor – no stream, Shun Yi Olympic Rowing and Canoeing Park (Shunyi, Beijing) – no stream water Chaobai River, Water Sports Park (Shan Dong province) – no stream, Xia Si Canoe Slalom Course – Qingshui River **Costa Rica (1):** Pejibaye – Pacuare River **Czech Republic (7):** Ceské Vrbné Slalom Course (Ceské Vrbné) – Vltava River, Pilsen Whitewater Park (Pilsen) – Mže River, Roudnice nad Labem (Roudnice nad Labem) – Elbe River, Sopotnice Freestyle Spot (Brná) – Divoká Orlice River, Trnavka Slalom Course (Zeliv) – Trnavka River, Troja Whitewater Center (Troja)– Vltava River, Veltrusy Kanal (Veltrusy) – Vltava River **France (19):** Argentière Slalom Course (Blachière) – Durance River, Bourg Whitewater Course (Bourg Saint Maurice), Cergy Neuville Whitewater Stadium (Cergy), Cesson-Sévigné Whitewater Stadium (Cesson-Sévigné), Épinal Slalom Course (Épinal), Isle de la Serre, Espace Eau Vive (Porcieu-Amlagnieu), Millau Whitewater Stadium (Millau), Pau Whitewater Stadium (Pau) – no stream, Parc des Eaux Vives (Huningue), Reals Whitewater Course (Murviel-lès-Béziers), Saint Pierre de Boeuf (Saint Pierre de Boeuf), Slalom Ardeche (Les Crozes), Stade d'eau vive Du Rebech (Foix), Stade d'eau vive de Lannion (Lannion), Stade d'eau vive de Nancy (Nancy), Stade d'eau vive St. Laurent Blangy (St. Laurent Blangy), Stade d'eau vive Sarrebourg (Sarrebourg), Stade d'eau vive de Tournon Saint Martin (Tournon Saint Martin), Stade d'eau vive de Vichy (Vichy) **Germany (3):** Eiskanal (Augsburg, Bavaria) – Lech River, Kanupark Markkleeberg (Markkleeberg, Saxony) –no stream water source Markkleeberg See Lake**,** Zwikau (Zwikau) – Mulde River **Greece (2):** Evinos River Slalom Course (Gefyra Mpania) – Evinos River, Helleniko Whitewater Stadium (Elliniko) – no stream **Italy (3):** Ivrea Whitewater Stadium (Ivrea, Turin) – Dora Baltea River, Merano (Merano, South Tyrol) – Torente Passirio, Mezzana (Mezzana, Trentino) – Torrente Meledrio **Latvia (1):** Kazu Rapids (Valmiera, Vidzeme) – Gauja River **Netherlands (1):** Dutch Water Dreams (Zoetermeer, South Holland) – no stream **New Zealand (2):** Mangahao Whitewater Park (Shannon, Horowhenua District) – Mangahao River, Tekapo Whitewater Course (Lake Tekapo) – Tekapo River **Norway (1)**: Sjoa River – Sjoa River **Poland (2):** Krakow Whitewater Course (Krakow) – Wisla River, Nowy Sacz Whitewater Course (Nowy Sacz) – Dunajec River **Russia (2):** Channel CHP, Novogomyy, Tyumen, Tyumen **Slovakia (3):** Water Sports Center Cunovo (Cunovo, Bratislava) – Danube River, Liptovsky-Mikulas Slalom (Liptovsky-Mikulas, Liptov) – Vah River, Zilinsky klub vodakov (Zilina) – Vah River **Slovenia (2)**: Solkan (Solkan, Goriska)– Isonzo River, Tacen Whitewater Course (Medvode) – Sava River **Spain (2):** Parc Olimpic del Segre (La Seu d'Urgell, Lleida) – Segre River, El Canal de Aguas Bravas (Zaragoza, Aragón) – Ebro River **United Kingdom (7):** Canolfan Dwr Gwyn (Bala, North Wales) – Tryweryn River, Cardiff International Whitewater (Cogan, South Wales) – no stream, Cardington Slalom Course (Bedford, Bedfordshire) – River Great Ouse , Holme Pierrepont National Watersports Center

(Nottingham, Nottinghamshire) – River Trent, Lee Valley Whitewater Center (Waltham Abbey, Essex) – no stream , Nene Whitewater Center (Northampton, Northamptonshire) – River Nene, Tees Barrage International Whitewater Course (Stockton on Tees) – River Tees **United States (52):** Adventure Sports Center Int. (Charlotte, North Carolina) – no stream, Avon Whitewater Park (Avon, Colorado) – Eagle River, Bear River Whitewater Improvement (Evanston, Wyoming) – Bear River, Blue River Whitewater Improvements (Breckenridge, Colorado) – Blue River, Brennan's Wave Project (Missoula, Montana) – Clark Fork River, Buck Creek Whitewater Park (Springfield, Ohio)– Buck Creek, Cañon City Whitewater Park (Cañon City, Colorado) – Arkansas River, Charles City Whitewater Park (Charles City, Iowa) – Cedar River, Clear Creek Whitewater Course (Golden, Colorado) – Clear Creek, Confluence Boatchutes (Denver, Colorado) – South Platte River, Dickerson Whitewater Course (Frederick, Maryland) – Potomac River, Durango Whitewater Park (Durango, Colorado) – Animas River, East Race Waterway (South Bend, Indiana) – St. Joseph River, Estes Park Whitewater Park – Big Thompson River, Farmington Whitewater Park – Animas River, Fort Worth Whitewater Park (Fort Worth, Texas) – Clark Fork, Trinity River, Frisco Whitewater Park (Frisco, Colorado) – Ten Mile Creek, Glenwood Whitewater Park (Glenwood Springs, Colorado) – Colorado River, Gore Creek Whitewater Park (Vail, Colorado) – Gore Creek, Green River Whitewater Park (Green River, Wyoming) – Green River, Gunnison Whitewater Park (Gunnison, Colorado) – Gunnison River, Horsehoe Bend Gutter Boatchute and Fish Passage (Horshoe Bend, Idaho), Kelly's Whitewater Park (Cascade, Idaho) – Payette River, Kent Whitewater Park– Cuyahoga River, Lawson Hole (Lawson, Colorado) – Clear Creek, Lock 32 Whitewater Park (Pittsford, New York) – Erie Canal Spillway, Longmont Whitewater Park (Longmont, Colorado) - St. Vrain River, Lyons Valley Park (Lyons, Colorado) – St. Vrain River, Matt's Kayak Course (Boulder, Colorado) – Boulder Creek, Nantahala (Bryson City, North Carolina) – Nantahala River, N. Platte Improvement (Casper, Wyoming) – North Platte River, Ocoee Whitewater Course (Cleveland, Tennessee) – Ocoee River, Ogden Kayak Park (Ogden, Utah) – Ogden River, Ouachita River Whitewater Improvements (Malvern, Arkansas) – Ouachita River, Pitkin County Whitewater Park (Aspen, Colorado) – Roaring Fork, Pueblo Whitewater Park (Pueblo, Colorado) – Arkansas River, PWCA Facility (Auburn, California) – North Fork American River, Riverside Park (Kernville, California) – Kern River, Rock Park (Sparks, Nevada) – Truckee River, Rollins Park (Pagosa Springs, Colorado) – Uncompahgre River, Salida Whitewater Park (Salida, Colorado) – Arkansas River, South Main River Park (Buena Vista, Colorado) – Arkansas River, South Platte Park (Columbine, Colorado) – South Platte River, Steamboat Whitewater Park (Steamboat, Colorado) – Yampa River, Stoneycreek Whitewater Park (Ferndale, Pennsylvania)- Stoneycreek, Rio Vista Whitewater Improvements (San Marcos, Texas) – San Marcos River, Trinity River Whitewater Feature (Dallas, Texas) – Trinity River, Union Avenue Boatchutes (Littleton, Colorado) - South Platte River, US National Whitewater Center (Charlotte, North Carolina) – no stream, Wasau Slalom Course (Wasau, Wisconsin) – Wisconsin River, Williamston Whitewater Park (Williamston, Michigan) – Red Cedar River, Wingfield Whitewater Park (Reno, NV) – Truckee River

Figure 31. The power surface index measure of whitewater difficulty through time and the four main types of whitewater designs: Slalom Olympic courses, slalom courses, whitewater parks, and non-Olympic recirculating courses.

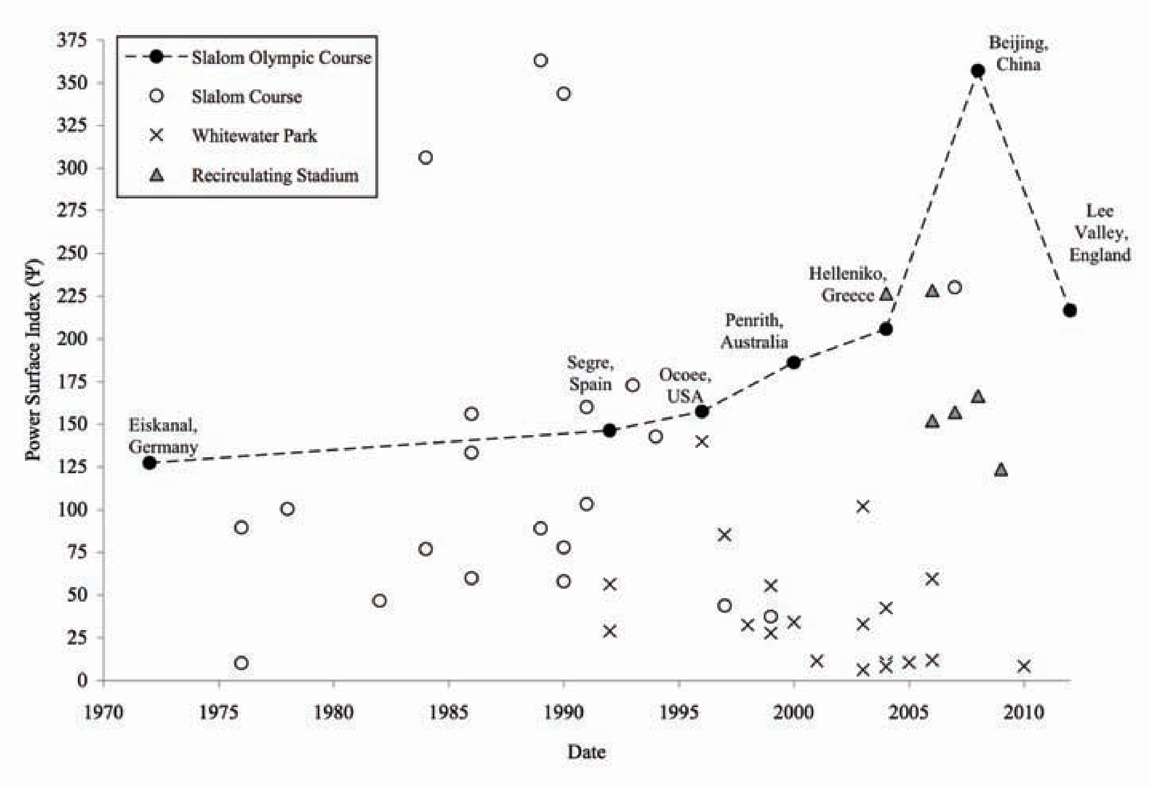


Figure 32. The 1972 Augsburg Olympic whitewater slalom course with low water flow showing the shape of the channel bottom. Photo by Thorsten Hartmann.

Figure 33. Spectators watch the 1972 Olympic slalom race on the Eiskanal (Sport München 1972).

Figure 34. Tom Johnson directs the placement of a large boulder (a) and slalom athletes move a rock into place in the Kernville (b). Photos compliments of Tom Johnson.

Figure 35. Confluence park on the South Platte River in Denver, Colorado. Photo by the author.

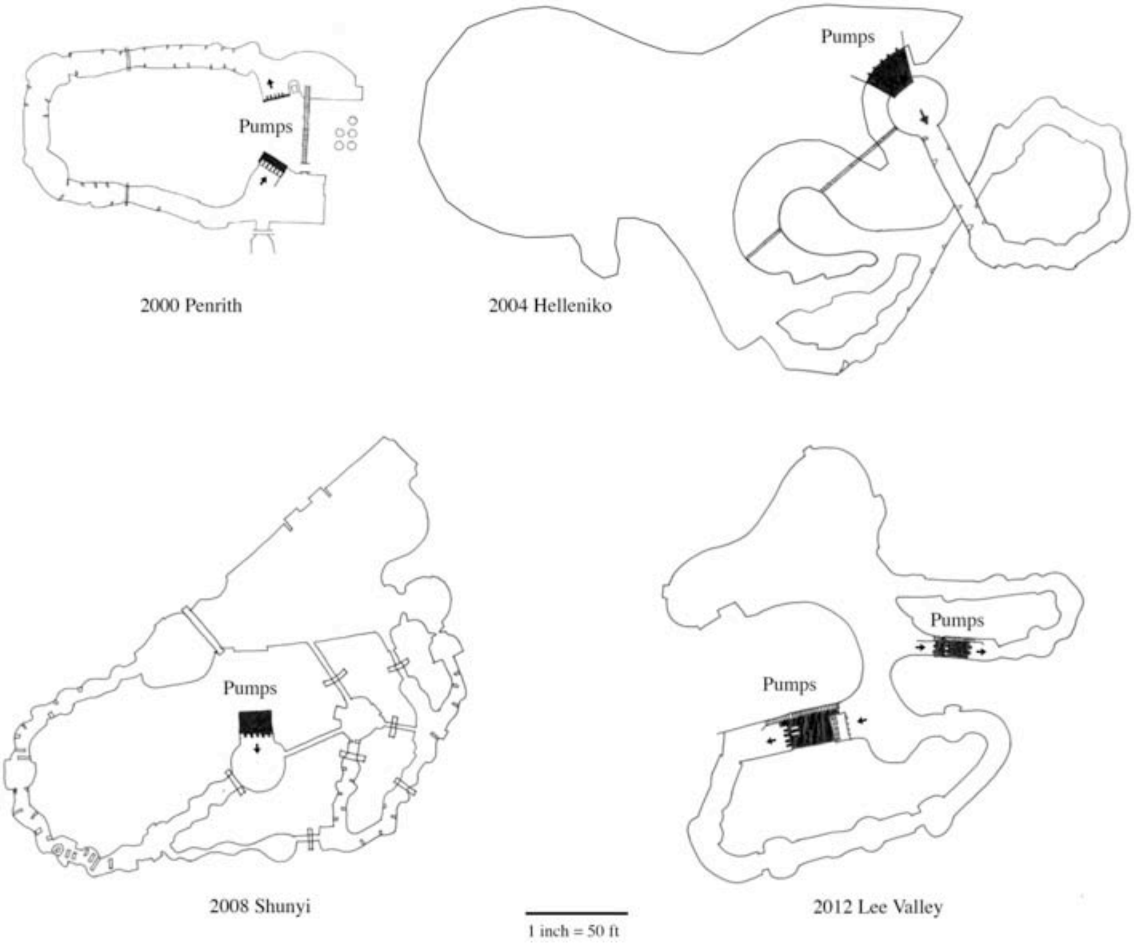
Figure 36. Dickerson Slalom Course is in an outflow from a coal-fired power plant in a diversion channel off of the Potomac River, Maryland, USA. Photo by Joe Jacobi.

Figure 37. Ocoee whitewater course during the 1996 Olympic Games. Photo by Richard McLaughlin.

Figure 38. Freestyle competition during the Teva Outdoor Mountain Games at the Vail Whitewater Park in Colorado, USA. Photo by Stephen Wright.

Figure 39. A multifunctional fish passage, water diversion, and whitewater design on the American River in Auburn, California. The whitewater channel or hydraulic chute channel is to the right in the image. Photo compliments of McLaughlin Water Engineers.

Figure 40. The shape of the four Olympic recirculating courses built since the year 2000: Penrith, Helleniko, Shunyi, and Lee Valley. The shaded areas indicate the pumps and arrows represent the direction of the water flow.



2000 Penrith

2004 Helleniko

2008 Shunyi

2012 Lee Valley

Appendix B. Key attributes and physical dimensions of fifty-five designed whitewater sites from 1965 to 2010, sorted by date built (* site in Goodman and Parr, 1994, Q is discharge, † for concrete channels).

#	Date	Country	Site Name	Purpose	Type	Length (m)	Mean Width (m)	Q (m3/s)	Slope	Head	Power surface index
1	1965	France	Vichy*	slalom, park	diversion	360	5	5	0.010	3.6	97
2	1972	Germany	Eiskanal	olympics	diversion	603	9	10	0.011	6.6	127
3	1976	Czech Republic	Troja WW Center*	slalom	diversion	700	11.5	20	0.009	3.6	89
4	1976	United States	Wasau Slalom Course	slalom	diversion, dam	427	11	18	0.014	0.5	10
5	1978	Czech Republic	Liptovsky Mikulas*	slalom	diversion	700	8	15	0.011	7.5	100
6	1982	England	Cardington Slalom Course	slalom	diversion	120	5	2	0.011	1.4	47
7	1984	Czech Republic	Trnavka Slalom Course*	slalom	diversion	479	10	15	0.020	9.8	306
8	1984	United States	East Race Waterway	slalom	diversion, dam	572	9	13	0.006	3.3	77
9	1986	Wales	Canolfan Tryweryn*	slalom	diversion	572	9	11	0.026	14.6	156
10	1986	England	Holme Pierrepont Center*	slalom	diversion	700	15	28	0.005	5.0	133
11	1986	France	St. Pierre de Boeuf*	slalom	instream	700	10	12	0.010	7.0	60
12	1989	France	Bourg-St Maurice	slalom	instream	330	12	25	0.035	11.5	363
13	1989	United States	Durango WW Park	slalom	instream	91	12	20	0.010	1.0	89
14	1990	Slovenia	Tacen	slalom	diversion	182	12	15	0.027	5.0	343
15	1990	France	Saut de Sabo WW Course	slalom	instream	600	30	70	0.003	2.0	78
16	1990	United States	Matt's Kayak Course	slalom, park	instream, dam	364	9	11	0.010	3.6	58
17	1991	France	WW Course of Reals	slalom	instream	400	18	40	0.014	5.6	160
18	1991	United States	Dickerson WW Course	slalom	diversion, power plant	258	11	11	0.010	2.6	103
19	1992	Spain	Seu d'Urgell*	olympics	diversion	300	10	12	0.022	7.0	146
20	1992	France	Lannion	park	slalom	300	12	15	0.009	2.7	56
21	1992	United States	Union Avenue	park	instream, water diversion	391	50	23	0.013	5.0	29
22	1993	France	Argentiere Slalom Course	slalom	instream	450	18	70	0.009	4.0	173
23	1994	England	Teeside*	slalom	diversion	250	7	10	0.010	2.5	143
24	1996	United States	Ocoee WW Course	olympics	instream	415	31	45	0.022	9.0	157
25	1996	France	Saint Larent Blangy WW Stadium	park	diversion	300	12	12	0.014	4.2	140
26	1997	France	Nancy	park	instream	330	16	20	0.014	4.5	85
27	1997	France	Sarrebourg	slalom	park	100	8	7	0.010	1.0	44
28	1998	United States	Clear Creek WW Course	park	instream	199	20	11	0.012	2.3	32
29	1999	United States	Salida Whitewater Park	park	instream	361	28	34	0.009	3.3	55
30	1999	France	Cesson WW Stadium	slalom	instream	300	10	12	0.006	1.9	37
31	1999	United States	Gore Creek WW Park	park	instream	75	13	21	0.013	0.3	28

32	2000	France	Cergy	park	instream	250	9	16	0.017	4.2	294
33	2000	Australia	Penrith Whitewater	olympics	recirculating	300	14	14	0.018	5.5	186
34	2000	France	Millau	park	instream	335	14	16	0.006	2.0	34
35	2001	United States	Ogden Kayak Park	park	instream	75	22	7	0.007	0.5	11
36	2003	United States	Forth Worth WW Park	park	instream	114	8	8	0.115	2.3	102
37	2003	United States	Blue River WW Park	park	instream	323	7	3	0.018	5.8	33
38	2003	United States	Green River WW Park	park	instream	392	27	34	0.001	0.4	6
39	2004	Greece, Athens	Helleniko WW Stadium	olympics	recirculating	350	15	18	0.017	6.0	206
40	2004	China	Nanjing WW Course	slalom	recirculating	314	9	16	0.013	4.0	113
41	2004	United States	Wingfield WW Park	park	instream	662	19	21	0.008	5.0	42
42	2004	United States	Rollins Park	park	instream	106	26	14	0.004	0.4	11
43	2004	United States	Lyons Valley Park	park	instream	631	14	6	0.004	2.5	8
44	2005	United States	Pueblo WW Park	park	instream	660	37	17	0.005	3.0	10
45	2006	United States	US National WW Center	commercial	recirculating	300	14	15	0.021	6.4	229
46	2006	Germany	Kanupark Markkleeberg	commercial	recirculating	270	12	19	0.020	5.3	152
47	2006	United States	Steamboat WW Park	park	instream	210	13	18	0.009	1.8	59
48	2006	United States	South Main River Park	park	instream	146	75	21	0.008	1.2	12
49	2007	Italy	Ivrea	competition	instream	234	13	20	0.032	7.0	230
50	2007	United States	Adventure Sports Center	commercial	recirculating	492	18	17	0.017	8.4	157
51	2008	China	Shunyi Canoeing Park	olympics	recirculating	300	9	17	0.021	5.5	346
52	2008	France	Pau WW Stadium	commercial	recirculating	300	15	15	0.017	5.0	167
53	2009	Netherlands	Dutch Water Dreams	commercial	recirculating	300	17	12	0.017	5.0	124
54	2010	United States	Buck Creek WW Park	park	instream	137	32	28	0.002	0.3	8
55	2012	England	Lee Valley	olympics	instream	300	11	15	0.018	5.5	250

Chapter 6

Cooling-off in Engineered River Parks: Park Use, Users’ Perceptions, and Multifunctional Design Considerations

Abstract

Urban parks with engineered waves built in a river as a recreational amenity represent a new type of park. Although they are becoming increasingly common and widespread throughout the nation, in part because of their positive economic impacts, there are few studies addressing the nature and extent of park use, the physical factors influencing park use, or park users' perceptions. I made observations of summertime park use and conducted surveys of park visitors to understand whether people's perception of the parks fits with ecological considerations. I observed most park visitors were walking (38%), on the streambank (76%), and there were few sedentary park users (33%). Kayaking represented only two percent of park activities, and the number of daily kayakers related positively to streamflow in three of the six parks. Air temperature best predicted daily park use, and water temperature best predicted daily instream park use. These results indicate that engineered river parks originally designed for kayaking, serve summer 'beach' functions for families in cities—and this use is more important in terms of total number of users and impact on underserved communities. Visitors ranked clean water, a natural appearance, and the sound of water as the most important park attributes and did not object to seeing concrete in the river, suggesting a disconnect between perceived naturalness and actual ecological function. Finally, I identified site selection, streamflow management, and streambank design as key factors for creating popular parks with ecological design features.

6.1 Introduction

River parks with engineered whitewater features, often called ‘whitewater parks,’ ‘boating chutes,’ or ‘boater parks’ offer public recreational spaces for urban residents. Kayakers seeking to build waves close to home and planners and engineers interested in river restoration projects to improve recreation, aesthetics, and the ecological value of the river promote the creation of these parks, of which fifty-one have been built in the United States since 1974. Engineers design instream drop structures to concentrate the streamflow and form whitewater waves. The whitewater structures often replace unsafe water infrastructure, such as low-head dams. Park designers anchor large, flat boulders in the stream to provide places for sunbathing and to create eddies where boaters and tubers can rest. They line the steambanks with large boulders to stabilize the banks and create seating, and trails often parallel the park and are part of longer greenway trail systems. Some parks have recreational streamflow provisions, called ‘Recreational In Channel Diversions’ (RICDs) to augment the flow in the summer and ensure the continued functionality of the constructed whitewater.

A few studies focus on the economic benefits of the parks to local communities, but there is little information on park use or park user’s perceptions of the artificial whitewater. In a feasibility report for a proposed park on the Feather River in California, the authors noted a lack of information on existing park use and user characteristics and relied on estimates of supply and demand for whitewater boating in the project area and national demographics for non-motorized boaters (mainly Caucasian males with household incomes of >$40,000 annually, CA DOWR 2009). In an economic impact study on the Clear Creek Whitewater Park in Golden, Colorado, the Director of Public Works estimated boater visitation from his office overlooking the park and divided the season into three parts: high-peak (mid-May to mid-July), moderate-peak (mid-April to mid-May and mid-July to early October), and non-peak (early October to mid-April) (Hagenstad et al. 2000). His high-end estimate ranged from 30-200 boaters on a weekend day, and the low-end was 10-90 boaters on a weekday. The midpoint of each estimate times the daily expenditure and travel cost per boater was used to calculate $1.4-2 million per year in local revenue generated by the park. Two additional economic studies relied on the same boater use estimates to calculate economic benefits for proposed parks in Idaho and Ohio (Watson et al. 2009, Turner and Peterman 2008, respectively). A study on the park in Reno, Nevada calculated event and non-event use and expenditures in two ways, without gambling and with gambling: $1.9-4.1 million annually (Resource Concepts 2002).

The Clear Creek park economic study linked boater use with streamflow, and recommended a relatively high summer flow of between 17-28 cubic meters per second (cms) to maximize boaters’ use of the constructed whitewater. Based on the economic study and testimony that a streamflow of 28 cms provides intermediate and advanced boating and is ideal for elite paddling competitions, the city claimed a RICD of 28 cms in the park from 6 AM to 6 PM from May-July (District Court CO 1998). Similarly, studies on boater use of whitewater parks in Breckenridge and Vail, both in Colorado, relied on observations and interviews with kayakers to determine that streamflow explained 86% of the variance in boater visitation (Boaters Per Day=0.073*cfs – 0.279, Raucher et al. 2002). They predicted 38 boaters per day at the parks in June and this estimate was used to establish RICDs in both parks (Raucher et al. 2002). These past studies establish a link between whitewater parks, boater use, RICDs, and economic benefit, but while the whitewater designer may expect to design the river for kayakers, in actuality park use may differ from their expectations.

This study addresses the extent and nature of engineered river park use, the physical factors influencing use, and user's perceptions of the park. Specifically, who is using the parks and are they in the water or on the streambank? Are the park users physically active? Is streamflow the most important physical factor determining daily park use? What do park user's value the most in their park experience, 'natural' or artificial features, and how can this research inform future park design? To answer these questions, I conducted a literature review, surveys, and direct observation of park users in parks in Colorado and Nevada. The literature review contextualized this study within previous river recreation and urban park studies.

6.2 Background literature

There are only a few studies on urban river park use and perception. Southworth (1970) recorded use of the Charles River in Boston by boys for fishing, swimming, throwing rocks, jumping in, and social gathering. Kondolf and Yang (2008) recorded urban stream uses such as camping by homeless, fishing, water sports such as canoeing, tubing, and kayaking, and spontaneous use. They linked spontaneous use, not programmed by a park designer, to features along streams, for example 'adventuring' takes place on dirt trails along the streambanks, shallow spots with stepping-stones, and around culverts larger than one meter in diameter (Kondolf and Yang 2008). Gobster and Westphal (2004) studied the Chicago River greenway and identified important human dimensions: cleanliness, naturalness, aesthetics, safety, and access. Studies on river perception reveal that people prefer a natural appearance (Junker and Buchecker 2008, Gobster and Westphal 2004), a medium water level (Whittaker et al. 2005), trim riparian vegetation to prevent places for burglars to hide (Purcell 2006), no large wood in the channel (Chin et al. 2008), and stable streambanks (Kondolf 2006, Wohl 2005).

Many studies on the motivations for river recreation have been conducted on rivers outside of cities in National Parks, Wild and Scenic Rivers, and rivers with recreational flow releases popular with boaters. These studies addressed the perceived crowding and a river's carrying capacity, or the number of boaters, fisherman, or tubers a river can handle at one time without degrading a single user's experience (Gimblett et al. 2001, Becker 1981, Manning 1980, Shelby and Heberlein 1986, Heberlein and Vaske 1977). Studies on recreational use of three streams in Great Smoky Mountain National Park (Larson and Hammitt 1981) and the Upper Pemigewasset and Swift River Drainages (Glass and Walton 1995) both found that instream use was greatest in the afternoon on sunny, summer weekend days and recommended management strategies to reduce user conflicts and impacts to aquatic habitat, specifically salmon holding pools. Another set of studies, called instream flow studies, address the amount of streamflow preferred by various recreational groups. Studies show that instream recreational quality increases with streamflow to a point, and then decreased with further increases, described as an inverted-U relationship that varies by location, skill level of the recreational user, and the type of recreational use (Brown et a. 1991, Whittaker et al. 2005).

Most whitewater parks are located in cities, and these can be viewed as a subset of urban parks. Several factors influence park use, including: distance from home to the park, park user characteristics (age, gender, and ethnicity), maintenance and safety, size, access to toilets and drinking water, organized events, and aesthetics (Mowen 2010, Frumkin 2003). The closer a person lives to an urban park, the more likely they are to use it and be physically active (Cohen et al. 2007, Grow et al. 2008). Parks in high-density inner cities receive heavier use than parks in low-density suburbs (Loukaitou-Sideris and Stieglitz 2002). Parks that are easy to access, have trails, or have sports fields (with recent field improvements) encourage more physical activity, which in turn may reduce obesity (Tester and Baker 2009, Kacynski et al. 2008, Gobster 1992). Giles-Corti et al. (2005) found that access to large, attractive parks was related to higher levels of physical activity (64%). However, other studies found low physical activity in parks: 65% of parks users were sedentary in Chicago and Tampa parks (Floyd et al. 2008) and 62% of male and 71% of female park visitors in Los Angeles parks (McKenzie et al. 2006). More men frequent parks and plazas than women, and more adults than any other age group (Mozingo 1984, Floyd et al. 2008). Black and Latino populations and lower income populations have poorer access to parks and recreation facilities (Wolch et al. 2005, Furuseth and Altman 1994, Dwyer and Hutchison 1990). Fear of crime can be a barrier to park use, and parents control their children's visitation based on their sense of neighborhood safety around a park (Mowen et al. 2005, Miles 2008). Observation studies of urban park use typically involved one-hour observation periods for more than one hundred total hours of observation (Table 7).

6.3 Methods

6.3.1 Study sites

I refer to the six parks by the name of the city where each park is located, instead of using the longer official park names (*Confluence Boatchute*, Denver, Colorado; *Pueblo Whitewater Park*, Pueblo, Colorado; *Clear Creek Whitewater Park*, Golden, Colorado; *Matt's Whitewater Course*, Boulder, Colorado; *Salida Whitewater Park*, Salida, Colorado; and *Wingfield Whitewater Park*, Reno, Nevada). These parks represent different geographic settings from the plains to the mountains, but were all designed by, or designed with advice from, engineer Gary Lacy (Recreation, Engineering, and Planning), and thus have a similar design style (Figure 41). The drops are U-shaped concrete and boulder structures, except at the Denver Park where the drops are entirely concrete. The Denver, Pueblo, and Reno parks are located within cities with populations over 100,000, are at lower elevations, and cost more to build per foot of park than the other parks (Table 8). These parks replaced dams or created 'boating chutes' around a dam. Denver is the shortest park at 76 m., with the whitewater features built in a boating chute adjacent to a rubble dam and directly upstream of the confluence with Cherry Creek. Reno is the longest park, at 792 m. with two channels flowing around an island and eleven individual drop structures. In the Pueblo Park, 20-meter tall levee walls line the edges of the Arkansas River, a smooth concrete wall on the left and a rock wall on the right with a set of steep stairs. The Pueblo park experiences the largest flood flows of any of the parks and has required repair due to erosion and undermining of a drop structure after high flows of 113 cms in 2006. The river park was closed during the 170 cms flood flows in June 2010 to anyone without proper equipment and experience (Woodka 2010).

The Boulder and Golden parks are located in the front range of the Rocky Mountains on comparably sized watersheds (98 and 77 km. long rivers, respectively). Dense riparian vegetation shades the river right bank of Boulder Creek and the trail alongside the creek is narrow and less than 1.5 m. wide in sections. The river left bank is steep, less vegetated, and shows evidence of past alteration for Boulder Canyon Road, which runs parallel to the park. I observed park use only in the section of Matt's Whitewater Course along Boulder Creek and the upper section of the Golden park, from the library whitewater feature to the most upstream features. Both cites extended the whitewater features downstream through the downtown areas. Boulder was the least expensive park ($50,000 initial construction) and has the smallest streamflow. The Golden park is accessible primarily from the river left where a trail parallels the creek and via a pedestrian bridge that connects with a nearby park.

The Salida park is the only park located at a high-elevation, in a small mountain city, and has the fewest drop structures. A riverside trail runs through the park, but unlike the other parks does not extend upstream or downstream of the park. There are four whitewater parks on the Arkansas River in Colorado; two of which I studied, Salida and Pueblo (Figure 42). The river supports more commercial rafting than any other river in the nation with approximately 250,000 boaters annually (Arkansas Headwaters Recreation Area 2009). Additionally, Salida hosts the 'First in Boating on the Arkansas' (FibArk) festival, the oldest annual paddling festival and kayaking competition in the nation. In reaches of the Upper Arkansas River located between cities, river managers regulate commercial river use to limit crowding, conflicts between users, and negative ecological impacts. A recreational streamflow of 19.8 cms is maintained from July 1-August 15 for continued boating through the end of the summer. This level reflects a compromise between the preferred flow for boating (31.2-42.5 cms) and the preferred flow for fishing (12.7 cms, Naeser and Smith 1995).

6.3.2 Surveys

On-site surveys of park users were conducted in June 2009 at all parks except Reno, due to time constraints. Surveys were conducted face to face in either English or Spanish with people over the age of ten using a stratified random sample method. The surveyor walked from the upstream to downstream end of each park alternating from users located in the stream to users on the streambanks and trails. No screening of the subject population occurred except for the minimum age (10 years old). For those recreating in the river, the surveyor approached respondents either when they were in an eddy or pool, or when they were entering or exiting the water. When groups were approached each member of the group was asked to fill out the survey independently. In all, I collected 277 surveys, with about fifty per park (Golden n=62, Denver n=58, Boulder n=53, Salida n=50, Pueblo n=46), with a refusal rate around 10%. The survey included 26 questions: 24 closed-ended questions on park use, user demographics and perception questions aimed at recreational and ecologically relevant features, and 2 open-ended questions about what visitors liked and disliked about a park. Responses to the open-ended questions about were transcribed and categorized based on common themes. I used a Likert scale to rank the perception questions from one to five, one being the most important and five not important.

6.3.3 Observations of park use

The following summer, I conducted systematic observations of park users in the same parks, plus one additional park (Reno) from May through September 2010 using a modified

System for Observing Play and Recreation in Communities (SOPARC) method (McKenzie et al. 2006). Along with a research assistant, I made observations on sunny days, over one-hour time periods, four times a day (10:00 AM, 12:00 PM, 2:00 PM and 4:00 PM). We adopted a marginal-participant vantage point from which we could observe park users, without being obvious, so that park users would not change their behavior due to being observed. Each park was divided into target areas from upstream to downstream, where the researcher could see the park users in a small section of the park (mean=10 target areas/park, Appendix A). Target areas were scanned from left to right in the same rotation order during each observation period, and we visited each park during at least one weekend day and one weekday in June and July, except the Reno park in June and the Pueblo park due to low visitation (Denver n=6 days, Pueblo n=3, Boulder n=5, Golden n=5). Additional observations were made at the Salida park in May (n=9), and the Reno park in May, August, and September (n=8).

In total 36 observation days, 148 hours, were conducted with two special event days during the FibArk festival in the Salida park (June 18-19), and a holiday weekend in the Golden park (Memorial Day, May 30-31). We recorded a park user's age, sex, activity engaged in, and ethnicity using a coding system. We sought to avoid double counting of visitors moving between target areas by making observations in an upstream to downstream fashion and keeping track of people already counted. If a park user engaged in an activity not included in the coding system, we recorded them as 'other.' We recorded the daily streamflow (USGS stream gauges), maximum daily air temperature (NOAA records), and we measured the water temperature after each observation period and calculated the average daily water temperature (YSI Model 55). Finer scale spatial patterns of park use were explored by making behavior maps of visitors in the Reno park over two weekend days (August 30-31, 2008).

6.3.4 Data analysis

To understand the spatial aspect of park use and where different uses occurred, I calculated the busiest target area and discuss how specific park features attracted visitors. I estimated the energy expenditure for park users by assigning a value (MET is the ratio of working metabolic rate to standard resting metabolic rate) to each activity and then summed the number of users in each activity type (Ainsworth 2000). I used a multiple regression (ordinary least squares) analysis to determine which physical factor predicted daily park visitation. I log transformed the daily park use and daily streamflow values to normalize the data, and excluded nine outliers: the observations made during the FibArk festival (n=2), Memorial Day weekend in Golden (n=2), days when the air temperature was less than 70 degrees Fahrenheit (n=2), and all three observation days from the Pueblo Park (n=3). There were only 18, 21, and 53 park users observed per day in Pueblo in June, the fewest people in any park. Twenty-seven observation days, or 108 hours of observation, was included in the regression analysis. The physical factors in the regression were streamflow, air temperature, and water temperature, and these independent variables were not significantly correlated (tolerance levels >0.5). The observation date did not correlate as strongly with daily park use, and was not included in the regression (Pearson 0.478, p=0.004). A second regression model tested the same independent variables as predictors of daily instream park use.

6.4 Results

6.4.1 Self-reported park use

The demographics of park visitors to the five parks were similar in gender, age, and income ($p>0.001$, Table 9). The typical user was male (62%), adult (65%), with a median age of 31. The largest city, Denver, had the most racially diverse park visitors (76% Caucasian), and the smallest city, Salida, had the least (94% Caucasian). Park users had a range of annual family incomes, with 26% making less than $25,000, considered below the poverty threshold for a family of five ($25,790 U.S. Department of Health and Human Services 2010), while 20% made more than $101,000 annually. This low-income use of the parks conflicts with findings from past studies that parks and greenways in particular primarily serve higher income neighborhoods (Wolch et al. 2005, Furuseth and Altman 1994, Dwyer and Hutchison 1990). Park visitors went to the park on a weekly basis (43%), or were visiting for the first time (27%), and stayed in the park for two hours or less (63%) during the summer season (51%, Table 9). There was no significant difference in activities reported by park users between the five parks ($p>0.05$). The top three self-reported activities all occurred on the streambanks (in order): watching people or nature, walking, and sitting. The top three self-reported instream activities were kayaking, swimming, and tubing. Most people traveled to the park in a car (67%) or walked (21%). The park seeing the most diverse transportation, Denver, had 27% of visitors walking, 25% biking, and 8% riding a bus to the park. Median travel distance to reach the parks was 10 miles, and the greatest distance traveled was 2,000 miles (mean=115 miles, standard deviation=321 miles). Most park users live locally, particularly in Pueblo where more than half of the park visitors live within five miles of the park. More than 20% of park users visiting the Boulder and Salida parks live more than 100 miles away. In contrast, less than 10% of visitors to the Golden, Denver, and Pueblo parks traveled more than 100 miles to the park.

6.4.2 Observations of park use

We observed 23,794 park visitors in the six parks; the five parks surveyed the previous summer and one additional park, Reno (Table 10). The observations confirmed other studies on park use and were similar to the survey results: more men than women (55% and 45% respectively), more adults (54%) than any other age group, mostly Caucasian park users (82%) followed by Latino (14%), and more park users in the evening (33%). An average of 697 park users (standard deviation 530) visit the engineered river parks per day, excluding the festival, holiday weekend, and Pueblo Park data. The only significant difference in daily park use was between Pueblo and the other parks ($p<0.05$). The Golden park had the greatest average daily park visitation (774 park users/day, not including Memorial Day) and Pueblo had the lowest (31 park users/day). Reno, Denver, and Boulder had similar average daily visitation (655, 579, and 547 park users/day, respectively), and there were fewer people visiting the Salida park (281 users/day, not including the FibArk Festival weekend described in the ‘Study Sites’ section earlier). Reno had the largest range of park users (80 in May and 2,082 in July), and this was also the only park observed from May until September. The greatest number of park users in a single day (3,720 people on Saturday, June 19, 2010) occurred during the FibArk Paddling Festival. Similarly, visitation to the Golden park on Memorial Day weekend (1,637 people on May 31, 2010) exceeded the second busiest day in July by 632 users. Mean daily park visitation did not correlate with a city's population, the number of drops, park length, park area, date built, or cost (Spearman Rank correlation >0.5).

We observed that the majority of park users were on the streambank (76%), which is a much higher percentage than reported in the survey (29%)(Table 9). The top-three activities took place on the streambanks: walking (38%), sitting (21%), and standing (11%). The next three most popular activities took place instream: wading (10%), swimming (5%) and tubing (4%). On one observation day, the number of instream park users exceeded streambank users in Denver (496 vs. 373, respectively on July 17). This occurred on a day when the Chatfield Dam upstream was undergoing repairs and streamflow was dropped suddenly to only 1.47 cms, about half the flow through most of July (USGS gage 06710247). At the same time, the air temperature was 102˚ F and water temperature was 80.6˚ F making it the warmest water and air temperature day recorded throughout the summer. The park was more heavily visited as the air temperature became hotter (Adjusted $R^2= 0.51$, $F_{3,27}=8.54$, $p<0.05$, significant variables shown in Table 11), and more people went into the water as the water temperature warmed up (Adjusted $R^2= 0.59$, $F_{3,27}=13.5$, $p<0.005$). Interestingly, as the streamflow dropped toward the end of the summer in parks without recreational flow provisions, an increasing number of park users, especially children, went into the water (Figure 43).

Only 33% of park users were sedentary for all the parks; however, the ratio of vigorous, walking, and sedentary physical activity varied in each park (Table 12). There were more sedentary park users in the Salida and Reno parks (37% and 34%, respectively, excluding the FibArk Festival in Salida), while the Golden, Denver, and Boulder parks all had a high percentage of walking-level park use (68%, 62%, and 62%, respectively, excluding Memorial Day). The amount of sedentary park use increased drastically during the FibArk festival, since the river was essentially closed-off for the paddling competitions, thus limiting the number of people in the water and the streambanks were so crowded that it would be difficult to run or bike on the trail. There were more men and boys engaged in vigorous activity compared to women and girls (16% vs. 9%), and more children. Children were the age group most likely to recreate in the water (43%), and the kayakers were mainly adults (77%, Figure 44). The activity of 'watching people or nature' was one of the most popular self-reported activities, but we could not determine this activity in the observation study, as it seemed too subjective.

Surprisingly, we observed that kayakers represented only 2% of all park users (mean 11 kayakers/day), compared to 6.5% in the survey. The greatest number of kayakers per day was during the FibArk Festival (83 kayakers on June 18 and 110 on June 19), with the next three highest (47, 37, and 25 kayakers) also in Salida. The average number of kayakers observed (16 kayakers/day, standard deviation 23) is lower than the estimated range of daily boaters given in past economic impact studies (Hagenstad et al. 2000). The relationship between daily kayak use and streamflow was not significant for all the parks ($y=0.004*cfs+8.15$, $p=0.21$, excluding Pueblo and FibArk festival). Individually, kayak use was positively related to streamflow in Boulder, Reno, and Golden, and negatively related in Salida and Denver. The positive relationship for Boulder, Reno, and Golden when evaluated together was significant ($y=0.022*cfs–0.045$, $p<0.01$).

6.4.3 Relating park use to park design

Unlike a greenway where park users typically walk, bike, or skate along the river corridor on a trail, I observed that people tend to stay in one place or take multiple trips down a short section of whitewater in the engineered river parks. Paddlers and surfers pick their favorite wave and take turns surfing it. Sometimes they intentionally surf together on the same wave if it is wide enough. Kayakers often do not paddle upstream or downstream of the wave, but park as close as possible to their favorite spot and play in that one place, called 'park and play.' Part of the park is that paddlers are likely to meet other paddlers and there is the community aspect of surfing together. By watching each other surf, paddlers and surfers can learn new tricks, and have an audience to cheer them on as they try new maneuvers.

The whitewater waves attract paddlers, surfers, tubers, and swimmers, who in turn appear to attract riverbank spectators. As Gehl (1987) found in researching the use of urban plazas and other downtown spaces, people like to watch other people. A favorite spectator location in the river parks is wherever there is a concentration of people recreating in the river, typically at the most dynamic wave. This is also where people are likely to flip over in their kayak or fall out of their tube or raft and so is an exciting place to watch. In the Salida park, the busiest target area bordered a parking lot with a boat ramp leading into the water and dead-ending into one of the most popular waves. This wave is the location of the FibArk freestyle kayaking competition, and where spectators gather and watch paddlers perform maneuvers. This area was the busiest during both the festival and on non-festival days.

Other popular locations in the parks are where confluences, sandy beaches, and easy access from parking areas exist. The busiest target area in the Denver park was at the confluence of the South Platte River and Cherry Creek where a sandy beach formed. People would set up chairs and umbrellas in the sand and young children could safely wade into the water along the gradual slope of the sand bar with their parent watching from nearby. The busiest target area in the Golden park was also a beach along the streambank where kids could play in the sand and teenagers and adults could sunbathe and watch the kids. The Golden beach borders a large, free public parking lot, providing easy access via automobile. Unlike the Denver beach where the sand deposits from upstream sources, the Golden beach is artificially constructed. In the Boulder Park the busiest area was a large grassy lawn with picnic tables close to the river and the parking lot. Upstream, dense riparian vegetation shades the river and the trail paralleling the river is about a quarter the size of the trail downstream. Stopping to watch other people in the upstream section of the park is difficult because of the need to move to make way for others on the trail. There is also little sunlight reaching the trail or riverbank on river left, so people go to the sunnier river left bank despite having to cross a road and crawl down a steep, desire trails.

Detailed spatial patterns of park use emerged in the behavior maps of Reno park (Figure 45). Park users concentrated at the upstream and downstream ends of the mid-channel island, where the river splits and then confluences. At the downstream end, they congregated at a set of wide stairs with convenient seating and water access; this was the busiest target area during the observations and where teenagers and adults gathered to socialize and be in the shade of a large tree (Figure 46). Streambank users on the grass stayed primarily in the shade near large trees to the west of Arlington Street. People recreating in the water gathered in the river right channel between the first and second drop. This may be explained by the fact that this area is the closest to the free parking lot and there is a ramp down to the water that facilitates access. Moving further into the park from the parking lot requires crossing a busy street or crossing the channel by wading. Parents carrying inner tubes and coolers while helping their children walk to the park may prefer stopping as soon as they get to the water. Another explanation may be that the first drop on the river right channel is the most suitable for young children while the drops on the left channel are larger and not as attractive to smaller children or parents. One area in the Reno Park consistently devoid of people was downstream of Arlington Street on the river right channel. This target area (#3) has a tall concrete wall on the right side and a steep rip rapped bank on the left, limiting access.

6.4.4 Park users' perceptions

Park users valued 'clean water in the river', 'having a natural appearance', and 'the sound of water' as the most important park features (Table 13). The least important were: 'not seeing concrete in the river', 'flat rocks on the riverbank', and 'shade along the riverbank.' Park users differed on their valuation of three of the ten attributes between the five parks: 'having a natural appearance,' 'open views of the river,' and 'not seeing concrete in the river.' Boulder park users rated 'having a natural appearance' as the most important attribute (0.94), but ranked 'not seeing concrete in the river' as not important (3.70). 'Providing fish habitat' ranked below 'having waves and holes to play in,' in all of the parks except Golden where park user's also ranked 'not seeing concrete in the river' as important. Park users preferred a medium water level at the top of the banks (42%), but many people had no preference (17%).

In response to the open-ended questions about what park users liked and did not like about the parks, most positive responses fell into a few categories: the water, river, downtown location near people's homes, and good river play features. Some users specified that they came to watch the kayakers in the park. Others said spending time in the park was, "much better than hanging out in the mall" or "watching TV all day." The feeling that the park aesthetics and sound of water provided a peaceful break from the city was also expressed. Many people mentioned the movement of the water as their favorite park feature. Some responses appear to reflect a park's individual characteristics. Users talked about fishing only in Salida and Pueblo, the two parks where there were the most fishermen. Park users also talked about the sandy bottom only in the parks where there was a sandy beach (Golden and Denver).

Negative responses centered on poor water quality, an ugly or non-natural park appearance, and crowding in the park. There were numerous comments about poor water quality in the two large cities, Denver and Pueblo. Park users mentioned difficult river access in the Pueblo Park where the main access point is a steep stairway down a levee wall. Visitors to the Pueblo park talked about being afraid their car would be broken into while they were in the park, and said the park was "ugly" and "looks run down." On the positive side, park users in Pueblo said that it was, "one of the best things Pueblo has to offer," and a good place to "hang out with friends." Users discussed conflicts between fishermen and boaters in the Salida Park, tubers and other users in the Boulder Park, and off leash dog walkers and other users in the Golden Park.

6.5 Discussion

Our observations of park use indicate that use by families, represented by a wider range of ages and use over the entire summer, is more important than boaters use of the engineered river parks. Most park users recreated on the streambanks, and those recreating in the river engaged in activities that did not require special equipment (wading and swimming) or required less equipment (tubing) than kayaking. The Salida park had the greatest number of kayakers, reflecting the role of the Arkansas River as a destination paddling location. One explanation for the difference in the most popular activity between the observations and user survey (walking and wading vs. watching people/nature and kayaking, respectively) may explained by the fact that the survey was conducted in the month of June only. June is prime kayaking season, with higher streamflow, and kayakers may attract others who come to watch. We were unable to capture the activity of watching in the observation study, and future study could specify whether watching people means watching kayakers specifically. Another explanation for the difference might be the survey method of alternating surveys between a streambank user and instream user over-represented kayakers. The other two most popular activities on the streambank (walking and sitting) and instream (swimming and tubing) matched between the observation and survey study.

Observation studies have limitations; they only show a snapshot in time and this study was limited to summertime use on sunny days between the hours of 10 AM and 5 PM. Observing park use earlier in the morning and later in the evening, during cloudy days, or during other seasons would provide additional information on park use patterns. Specifically, fishermen may have been underrepresented because they may prefer to fish just after sunrise and before sunset on cloudy days or when other people are in the water potentially scaring the fish away or toward the stream bottom. Despite the limitations, I found that on hotter days there were more people in the parks, and when the water was warmer more people went into the river. Park visitation is the highest during holiday weekends and festivals as past economic studies indicated. Compared to other urban parks, people in the whitewater parks are physically active suggesting the parks may contribute to more active living. However, females and seniors were more sedentary, which is consistent with past studies.

The three most valued park features identified by users (clean water, a natural appearance, and the sound of water) were similar to the human dimensions identified in past river perception studies (Junker and Buchecker 2008, Gobster and Westphal 2004). Sound is not a visual aesthetic, but can be considered an aspect of a park's aesthetic. Park user's valued clean water but their use of the Denver park shows an unawareness of the actual water quality. The South Platte River and Cherry Creek exceed the limit for direct water contact recreation particularly during the summer due to E.coli bacteria levels, an indicator of fecal coliform or sewage. Bilingual signs at the confluence warn park visitors about the risk of water contact, yet there are hundreds of people in the river daily during the summertime and more children in Cherry Creek where the E. coli levels are typically higher. Park users may assume Cherry Creek is cleaner than the South Platte River because the water is clearer, or they may just make their decision to enter the water based on how hot it is regardless of the water quality and since the water depth is shallower there are more children in the creek.

Park visitors did not mind seeing concrete in the river, they valued the artificial whitewater waves above fish habitat and shade along the riverbank (riparian vegetation), and they preferred a medium water level in the river, which may all limit the ecological potential. As Junker and Buchecker (2008) found in studying people's perception of river restoration in simulated photographs, there is a difference between people's perception of naturalness and the eco-morphological criteria. The potential disconnect between the public's aesthetic and recreational preference for the river and the ecological quality is significant because creating multi-purpose parks is the goal for most of the engineered river parks, and designers consider both human and aquatic habitat needs in the park designs.

6.5.1 What makes a popular eco-river park?

I identified three elements that can make a river park popular while offering opportunities for incorporating river restoration: site selection, streamflow management, and streambank design. There are undoubtedly many other factors, but these appear to be the most important to attract park visitors and offer ecological design opportunities. If a park is centrally located in the downtown and easy to access it will attract visitors. I observed that easy access goes beyond the location of the park downtown and should include consideration of free and safe parking near the most popular park locations (confluences and sandy beaches) since the majority of park users travel by car. Access to sun, public toilets, and the river via a ramp add to the popularity of a park. Locating parks in cities in degraded reaches or reaches where bank stabilization is necessary may simultaneously eliminate potential environmental impacts, since urban rivers are typically highly impacted. Parks built outside of cities on river reaches with no pre-existing infrastructure will have more significant environmental considerations, especially given the lack of data on the biological impacts of the parks. The only biological opinion on the parks suggests that because the drop structures are similar to structures built in the stream for stream restoration they provide beneficial habitat for salmonids (McGrath 2003).

The expectation based on past studies, was that kayaking would be a primary activity and kayakers prefer higher streamflow. This study shows that kayaking represents a small user group and higher flows attracted more kayakers in Boulder, Reno, and Golden, but not in Salida and Denver. More paddlers may travel to the Salida park at the end of the summer when recreational flows on the Arkansas River are consistent and other rivers are too low. In Denver there were few kayakers perhaps because the boating chute is small and crowded with waders, swimmers, and tubers, and most of the kayakers I observed were beginners who prefer lower streamflow. Fixing the streamflow at a specific elevated summer level for kayaking (RICDs) may limit the recreation potential for other instream users who prefer warmer water temperature. Additionally, a fixed streamflow limits the ecological value of a variable flow regime since most rivers in Colorado and Nevada have snowmelt dominated hydrographs with high flows in the Spring and early Summer and lower flows in the Fall (Poff et al. 1997). RICD legislation is still disputed (Crow 2008), and more research is needed to determine how variable streamflow levels and water temperature interact to meet recreational instream use and aquatic life needs.

Since most park users are on the streambank, focusing on streambank design should be as important as the design of whitewater drop structures. Sandy beaches, whether naturally formed at a confluence or created by artificially added sand, create a popular place. However, the amount and area of sand needs to be evaluated alongside the risk of creating places where the host worm (*Tubifex tubifex*) for whirling disease parasites (*Myxobolus cerebralis*) that harm trout may establish in the fine sediment (Matt Kondratieff, CDOW personal communication). Trails need to be wide enough to allow spectators to stop and watch people in the river, and for people carrying boats or inner tubes to pass others on the trail. To make the trail more environmentally friendly, using pervious pavement and locating the trail alternately close to the river in places and further away in others may establish more valuable riparian patches of habitat with less human traffic. The streambank should provide both shady and sunny areas so people can modify their thermal comfort while still providing enough of an intact riparian corridor for wildlife to navigate and to sufficiently shade the stream. Decamps (2001) emphasized connecting ecological sustainability and cultural sustainability in riparian landscapes, since the "survival of riparian landscapes requires that people enjoy and take care of them" (p. 170). Finally, the streambank can be designed using hard engineering solutions for high traffic areas and biotechnical solutions where feasible for areas of riparian vegetation.

The importance of these three elements is evident in the park visitation to and perception of the busiest and emptiest parks, Golden and Pueblo. In Golden, the park blends into the downtown urban fabric, with the city hall, library, police department, community center, a city history park, and two additional urban parks touching the edges of the river park. The Pueblo park is located outside the downtown, and access is over a busy, long road bridge and a steep stairway along a levee wall. The adjacent land use on one side of the Pueblo park is a railroad yard. The park currently lacks a bathroom and parking is seen as risky and far from the water. The park in Pueblo competes with the downtown Arkansas Riverwalk, an urban amenity built in a diversion channel through the downtown that is similar in concept to the San Antonio Riverwalk. Streamflow management is complex, but there may be a relationship between channel width, or the relative size of the river, and instream use (Yang 2004). Large rivers like Pueblo may seem too intimidating for tubers, swimmers, and waders, who would have to swim a long distance to get back to the streambank and have a more difficult time maneuvering in the current. The bank design in Golden includes benches, shade, and niches where people can find a private place and other areas where people are excluded to maintain the riparian vegetation. Pueblo has few bank amenities, lots of sun exposure, and has an appearance that matches the channels primary design, flood control. What began with kayakers wanting whitewater close to home in Golden, grew into a "sacred place" in the community (Hester 2006) where a wide range of recreational uses coexist and people value a natural appearance that includes a priority on fish habitat and limiting the amount of concrete in the river.

6.6 Conclusion

The engineered river parks were originally conceived as river enhancements that would serve the kayaking community and potentially the aquatic habitat. This study shows the parks became important for a more diverse, non-whitewater user group consisting of mostly non-specialized recreational users on the streambank. The parks clearly provide social benefits: urban residents can cool down on hot summer days, be physically active, and connect with nature in the city. The biggest factor determining daily park use is the air temperature, as it gets hotter more people visit, and as the water temperature warms up more people get into the river. The parks attract large numbers of visitors, and past economic studies with higher numbers of kayakers probably underestimate the total economic benefit of these parks. While river managers focus on limiting river use on wilderness rivers to avoid crowding, it seems that planners and designers of urban river parks might focus on encouraging people watching, in essence adopting Jane Jacob's idea of eyes on the street into eyes on the river (Jacobs 1961). Places that are safe for children to play are places on the river where adults can supervise and react if someone gets into trouble. The parks need to become safe in terms of water quality as well, and this was evident in park user's values, but needs to be addressed in places like Denver where the water quality exceeds direct water contact standards. Careful site selection with good access, streamflow management, and streambank design can encourage park visitation and offers opportunities to incorporate ecological design into primarily recreation-focused design. Although most of the parks are termed whitewater parks, I refer to them as engineered river parks because they represent a resource for urbanites during hot summer days, not only kayakers surfing whitewater waves.

6.6 Literature cited

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Table 7. Park observation studies, ordered by total hours observed, with the current study included.

Study (Author, Year)	**Park Type**	**Total Obs.** (hours)	**Obs. Period** (hours)	**Obs. Date Range**	**# Parks**	**Total # Users**	**# Users/ hr.**
Ward et al. 2010	Urban Park	280	1	Spring-Fall	10	76,632	274
Golicnik and Thompson 2010	Urban Park	52	1	May 2002, 2003	3	9,636	185
Podolak 2010	Urban Park (Whitewater)	148	1	May-Sept.	6	23,794	161
Cohen et al. 2006	Urban Park	336	1	Dec. 2003-Feb. 2005	12	26,163	77
McKenzie et al. 2007	Urban Park	224	1	Dec.-July	8	16,244	72
Bradley 2010	Skate Park	13.3	0.33	-	2	613	46
Tester & Baker 2009	Urban Park (Sports Field)	112	1	May-June 2006, 2007	3	4,750	42
Mozingo 1989	Urban Plaza	12	4	October	2	400+***	33
Larson & Hammitt 1981	National Park (River Use)	260	1-2	June-Aug.	1*	5,851**	22
Loukaitou-Sideris 1995	Urban Park	400	2	May-June	100	8,427	21
Floyd et al. 2008	Urban Park	672	1	March-June	28	9,456	14
Giles-Corti et al. 2005	Urban Park	60	10	-	6	772	12
Gobster 1991	Urban Park (Trail)	26-50	.17-.33	9 months	1	5,496	109-219

* Three streams included in one National Park
** Estimated from graphs
*** Personal communication

Table 8. Attributes of the six engineered river parks. A dash indicates there is no recreational flow provision for that park.

Attribute	**Reno NV**	**Denver CO**	**Pueblo CO**	**Boulder CO**	**Golden CO**	**Salida CO**
Geography	Meadow east of Sierra Nevada Mountains	High Plains east of Rocky Mountains	High Plains east of Rocky Mountains	Foothills of Rocky Mountains	Foothills of Rocky Mountains	Rocky Mountains
Stream	Truckee River	South Platte	Arkansas River	Boulder Creek	Clear Creek	Arkansas River
City Population	220,500	598,707	104,877	94,258	17,159	5,396
Mean daily visitation	655	579	31	547	774	281
Elevation (m)	1,341	1,609	1,431	1,655	1,729	2,158
Date Built	2004	1974	2006	1990	1998	2000
Park Length (m)	792	76	655	213	620	271
Park Area (hectares)	2.85	0.59	3.91	0.99	1.46	2.01
# Drop Structures	11	8	8	8	7	4
Mean Daily Discharge May-Sept. 2010 (cms)	13.8	4.05	35.1	1.95	4.79	21.92
Kayaker Ideal Flow (cms)	8.50-28.3	5.66-141	8.50-113	7.08-14.2	11.3-28.3	31.2-42.5
Recreational Flow Provision (cms)	-	-	-	-	28.3 May-July	19.8 July 1-Aug 15

Table 9. Summary of park user demographics and activities collected during thirty-six observation days in the parks.

Variable		#	%
Gender	Male	13,201	55%
	Female	10,593	45%
Age	Child	4,455	19%
	Teen	3,934	17%
	Adult	12,734	54%
	Senior	2,671	11%
Race	White	19,436	82%
	Latino	3,336	14%
	Black	419	2%
	Other	603	3%
Bank Activities	Walking	9,083	38%
	Sitting	4,984	21%
	Standing	2,611	11%
	Biking	667	3%
	Running	267	1%
	Lying Down	291	1%
	Skating	83	0%
	Wheelchair	40	0%
	Other	119	1%
River Activities	Wading	2,496	10%
	Tubing	990	4%
	Swimming	1,193	5%
	Kayaking	578	2%
	Rafting	220	1%
	Surfing	124	1%
	Fishing	48	0.2%

Table 10. Visitation patterns of park users in five parks in Colorado: Denver, Pueblo, Golden, Boulder, and Salida. A chi-square test (X^2) of the difference in responses to the likert scale questions was significant for all questions ($p<0.05$) except the annual family income.

Survey Questions	**Responses**	**#**	**%**	**X^2**
How often do you visit this park?	First visit	74	27	68*
	Yearly	31	11	
	Monthly	45	17	
	Weekly	50	19	
	> than once/wk	65	24	
What time(s) of the year do you visit?	Summer	254	51	21*
	Fall	87	17	
	Winter	59	12	
	Spring	102	20	
How long do you stay (hours)?	<1	82	30	131*
	1-2	89	33	
	2-3	45	17	
	3-4	20	7	
	>4	31	11	
How do you travel to this park?	Car	181	67	537*
	Walk	56	21	
	Bike	18	7	
	Bus	5	2	
What is your annual family income ($)?	0-25,000	37	26	182
	26,000-50,000	32	22	
	51,000-75,000	22	15	
	76,000-100,000	23	16	
	101,000+	29	20	

Table 11. A multiple regression model indicates that air temperature is the most significant predictor of daily park use. When daily park use is divided into instream and on the banks, instream use is predicted by water temperature and bank use is predicted by air temperature.

Model 1 – Total Park Use

	B	*t*	*p*
Air Temperature (Celsius)	0.020	2.72	0.012*
Water temperature (Celsius)	-0.001	-0.132	0.896
Streamflow, Q (log)	-0.129	-1.23	0.230
N	27		
Adjusted R2	0.51		
F	8.54		
p	0.00054		

Model 2 – Instream Use Only

	B	*t*	*p*
Air Temperature (Celsius)	0.020	1.73	0.096
Water temperature (Celsius)	0.019	2.54	0.018*
Streamflow, Q (log)	-0.167	-0.992	0.332
N	27		
Adjusted R2	0.59		
F	13.52		
p	$2.7*10^{-5}$		

Model 3 – Streambank Use Only

	B	*t*	*p*
Air Temperature (Celsius)	0.018	2.47	0.022*
Water temperature (Celsius)	-0.007	-1.52	0.142
Streamflow, Q (log)	-0.116	-1.08	0.288
N	27		
Adjusted R2	0.280		
F	4.36		
p	0.014		

P<0.05*, P<0.005**

Table 12. Percent of daily park users engaged in different physical activity levels (sedentary, walking, and vigorous) by sex, age, and park. Physical activity levels determined by the ratio of work metabolic rate to a standard resting metabolic rate (MET, Ainsworth et al. 2000).

Activity Level	**Sedentary**	**Walking**	**Vigorous**
Activities (METs)	Sitting (1.3), Standing (1.5), Lying Down (1)	Walking (2), Wading (2.5), Fishing (3), Surfing (3), Tubing (3)*, Wheelchair (2)	Bicycling (6), Running (6), Kayaking (5), Rafting (5), Swimming (6), Skating (5)
All %	33	54	13
Sex: Male %	32	52	16
Female %	35	56	9
Age: Child %	22	60	19
Teen %	34	52	14
Adult %	35	53	12
Senior %	41	53	5
Park: Reno %	34	46	20
Boulder %	31	62	6
Denver %	25	62	13
Golden %	19	68	13

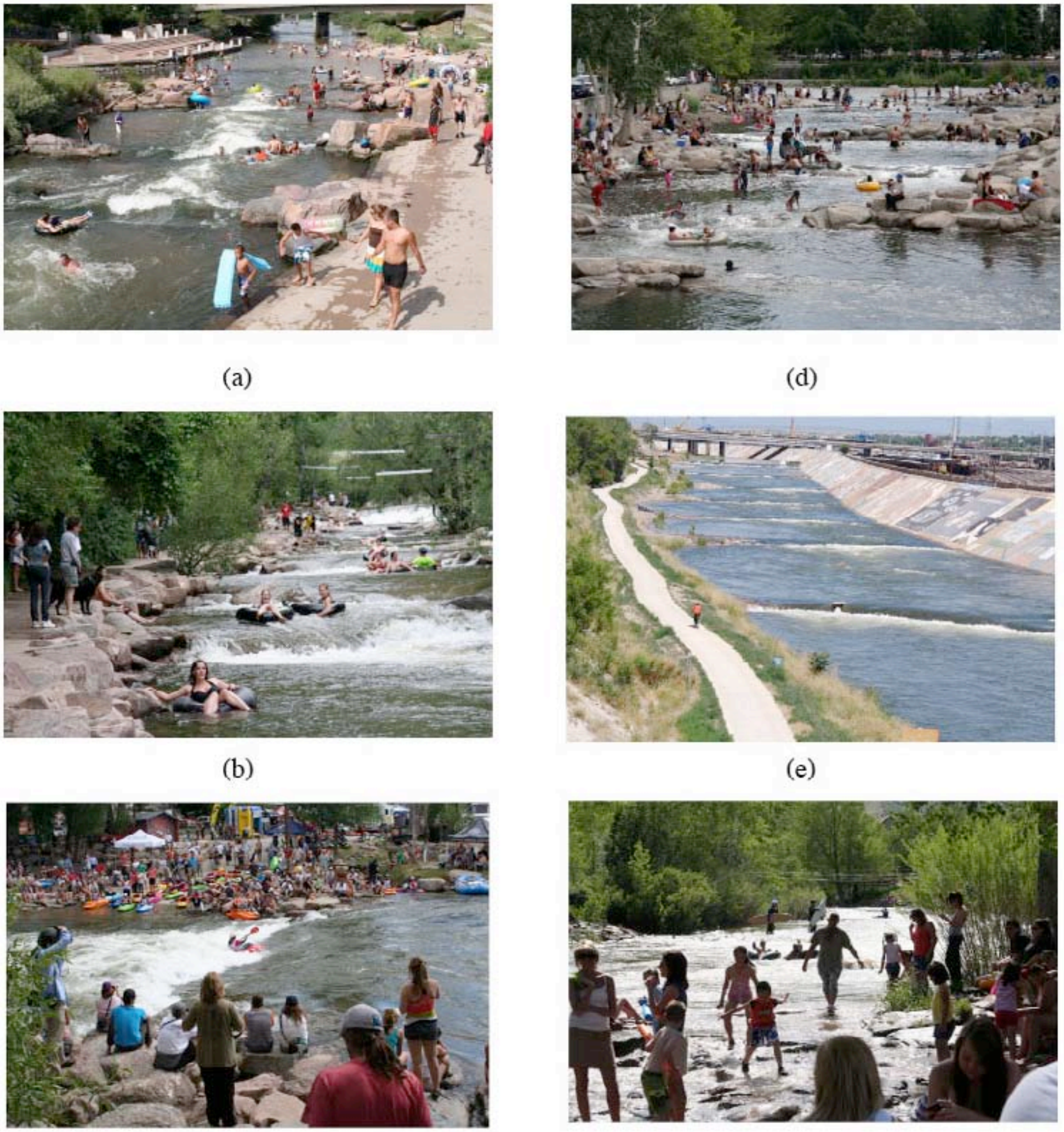
* Tubing MET personal communication B. Ainsworth 2010.

Table 13. Mean likert scale ratings of park and river features in the parks: 1 (very important) to 5 (not important).

Features	Denver	Pueblo	Boulder	Golden	Salida	All	F
Clean water in the river	1.08	1.48	1.06	1.13	1.60	1.27	4.40
Having a natural appearance	1.63	2.15	0.94	1.48	2.00	1.64	6.93*
The sound of water	1.47	2.15	1.43	1.50	1.63	1.64	3.23
Easy access to the water	1.76	1.87	1.13	1.76	1.94	1.69	1.69
Waves and holes to play in	2.05	1.54	1.58	2.05	1.92	1.83	1.01
Providing fish habitat	2.24	2.07	1.62	1.87	1.92	1.94	2.32
Open views of the river	1.97	2.11	2.23	1.79	2.02	2.02	5.04*
Shade along the riverbank	2.34	2.15	1.66	2.21	2.30	2.13	0.731
Flat rocks on the riverbank	2.20	2.26	2.06	2.15	2.06	2.15	4.19
Not seeing concrete in river	2.31	2.67	3.70	1.73	2.06	2.49	13.7*

*$P<0.001$

Figure 41. Photos from the river parks (a) Denver, (b) Boulder, (c) Salida during the FibArk festival, (d) Reno, (e) Pueblo, and (f) Golden during Memorial Day Weekend, photos by author, summer 2010.



(a) (d)

(b) (e)

(c) (f)

Figure 42. The study sites in Colorado and Nevada with additional engineered river parks and major river drainages indicated.

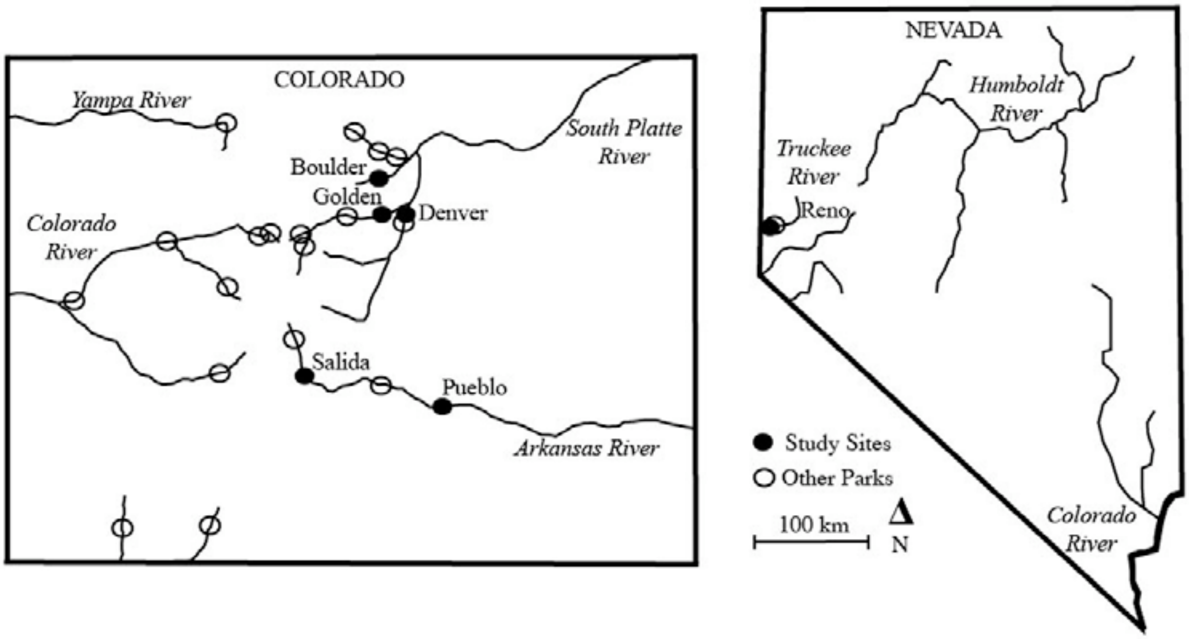


Figure 43. Children were the most likely to recreate in the river at the parks. View of an artificial wave in the river left channel of the Reno park below Arlington Street Bridge, photo by author, July 2010.

Figure 44. More people go into the water with warmer water temperature in the Reno park, photo by author, August 2010.

Figure 45. Behavior map of the Reno park indicating the position of instream users (dots) and streambank users (triangles) over a one-hour period in August 2008.

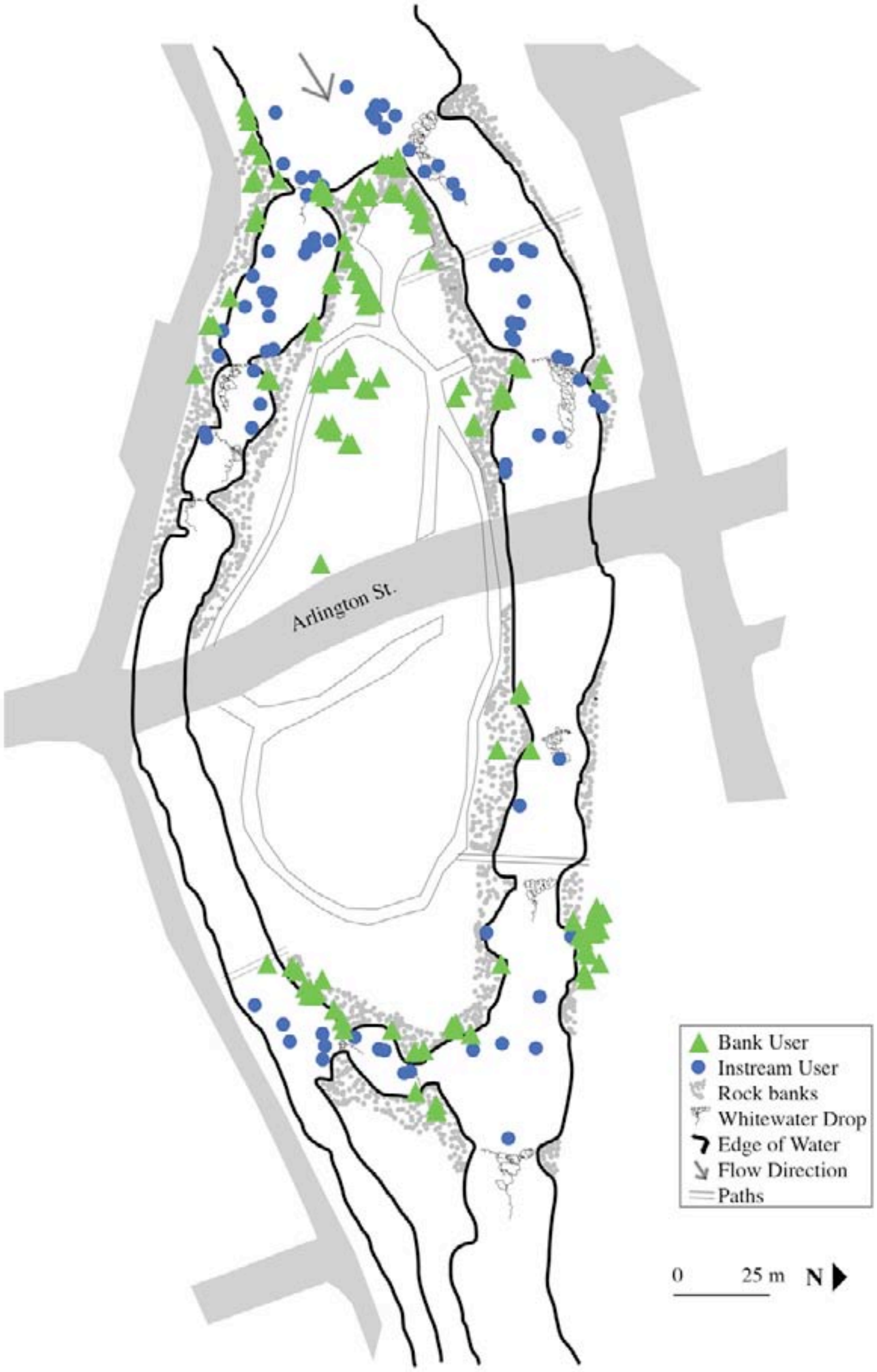


Figure 46. The busiest area in the Reno park where people gathered on the stairs and under the shade of a tree to watch the traffic float down the river, photo by author, August 2010.

Chapter 7

Conclusion

7.1 Overview of study results

People have designed water features throughout history; however, only within the last century have we tried to restore rivers to improve the ecology or improve habitat for a desired species while at the same time enhancing the natural beauty and recreational use. Rivers have always played a central role in cities, but in developed countries the functions have shifted from utilitarian to leisure and recreation following the industrial revolution (Kondolf and Podolak 2011). Instead of focusing on how rivers provide spaces for industry and dilute effluent the goal today is to reconnect people with urban rivers, revitalize downtown economies, and restore ecological function. These new hybrid riverscapes are judged based on how natural they look and reflect idealizations of nature. Brown's river features were one of the earliest examples of large-scale river design for aesthetics and recreation. Urban river restoration projects are a more recent example of multifunctional designs, with artificial whitewater at the end of the spectrum of riverscapes made for aesthetics and recreation. The transformation from industrial to consumptive riverscape design is being documented (Kondolf and Podolak 2011, Stevens 2009), but there is a lack of evaluation to determine how multiple functions work together in multifunctional riverscapes.

In this dissertation, I addressed some of the gaps in knowledge about the conflicts and synergies between social and ecological functions in riverscape planning and design to advance sustainable development of riverscapes. The individual studies addressed various types of riverscapes, with a similar theme explored in each—how do the social (aesthetic and recreational use) interact with the ecological function (biophysical processes)? This question is important because there is a lack of monitoring projects post construction to learn how to improve designs and uncertainty regarding whether multifunctional riverscapes accomplish their stated objectives. Even when a riverscape project does not include multiple functions in the project objectives, as in the case or some river restoration projects, I found evidence for an aesthetic influence.

There are some key differences in the study time-periods. Capability Brown's riverscapes were primarily for wealthy estate owners and a limited upper class invited to the property by the owner. Today, many of the estates are in the public trust and open to the public for a fee. In these riverscapes the water is prominently featured as a large, calm lake. In contrast, the 20th century stream restoration projects were ostensibly done to stabilize the channels and improve fish habitat and stream ecology more generally. The results show that even these ecological restoration designs have an aesthetic element in the symmetry and single thread channel alignments. Twentieth century urban stream restoration projects (Isar, South Platte, and Cheonggyecheon) and artificial whitewater projects are created mainly for public consumption as parks. These restoration projects are city improvements that serve as recreational and gathering spaces. Water flows in fountains or through drop structures such as the artificial whitewater waves. The intended users of these features (with the exception of the Cheonggyecheon where instream activities are mostly people dipping their feet in the water) are active, physically vigorous, recreational users who get into the river. This is opposed to the more passive use of looking at landscapes, such as Capability Brown's lakes and cascades. Although different in terms of the movement of the water and time period, the designs are all cultural landscapes where the human shaping of the river dominates. In the case of the 20th century river restoration designs for improved fish habitat, the cultural element is not openly acknowledged and the designs are purportedly based on geomorphic principles.

In the individual studies I found aesthetic-ecological and recreation-ecological intersections and discuss these as they offer directions for improved riverscape planning and design and directions for future study (Table 1). The research builds on past studies on river aesthetics, ecological river planning, and integrating recreation and ecology. Finally, I reflect on the limitations of multifunctionality and the need to view it as an appropriate planning and design approach for impacted rivers in developed areas.

7.2 Aesthetic-ecological conflicts

In chapter 2, I found that late 20th century river restoration designs matched the line of beauty in exhibiting almost perfect symmetry (Table 1). This study is the first to compare quantifiable variables of form in stream restoration projects to those in classic designed landscapes and in aesthetic theory. The difference in sinuosity and symmetry between the two sets of designs may be that the stream restoration projects involved full-scale rebuilding of the channel so the form could be imposed, whereas Capability Brown mostly flooded existing topography using dams. Brown may have been making scenographic and practical decisions about the form during the construction of the lakes. Even the river restoration idealized sinuosity values were too high to actually construct on site due to confinement of the channel, and changes were made during construction. High sinuosity does not equate to chaotic forms (Stolum 1996), as even high sinuosity can appear ordered if the bends are symmetrical and regular. The adaptation of an ideal form to the site conditions occurred in both Brown's riverscapes and river restoration projects. Although the site limited the realization of an ideal form, the river restoration projects studied had almost perfectly symmetry in the constructed meander bends. In addition to the symmetry, the river restoration designs all had single thread channels, as opposed to a braided channel pattern which existed in a few of the projects prior to restoration.

Often stream restoration success involves visual assessment of what the stream looks like, i.e. whether it looks more natural than its previous appearance, and my research suggests there are underlying cultural preferences for beauty in the meander designs. The line of beauty provided a measurable example of an aesthetic ideal; however, Hogarth did not list symmetry as a main principle of beauty, but wrote that it contributed to beauty in terms of fitness, one of his main principles. Future study could expand the analysis to include Hogarth's additional principles of beauty or expand to other relevant aesthetic theorists such as those of Edmund Burke (1757). It is also unclear whether the preference for symmetry in meanders is a North American phenomenon or whether it is apparent in other regions. It would be interesting to understand how geographic locations may influence people's channel pattern preferences, i.e. people either prefer streams that match the stream patterns in their local area or the preference is universal and not related to place. Future study could explore the preference for a single channel compared to a braided channel using photo comparisons, or channels with no, low, and high sinuosity.

The research could also be expanded along the lines of exploring an aesthetic influence on the science underlying meander forms. Luna Leopold (1994) argued rivers tend towards an ideal meander form, a sine generated curve, and he used illustrations of an ideal meander with symmetrical bends but did not explicitly state they should be symmetrical (Langbein and Leopold 1966). This finding is counter to research on rivers that shows asymmetry exists in natural streams (Carson and Lapointe 1983). Even when there is low sinuosity and the appearance of order in a stream it does not persist for a long reach of the stream and alternates with high sinuosity and chaotic appearing reaches (Stolum 1996). Leopold's selection of meander bends to study and develop his theory on ideal meanders deserves further study. The symmetry and regularity in the channel designs may be the result of Leopold's ideal meander science and the illustration of meander dimensions in scientific studies and restoration design guidelines as a single s-curve that is highly symmetrical and regular.

A form-based approach to channel design where the newly constructed channel is armored and trained into position limits the ecological function. Past research shows that dynamism in rivers, specifically actively migrating channels and instability, leads to ecological richness and diversity (Palmer et al. 2005, Wohl et al. 2005, Naiman et al. 1993). Restricting the river to a specific channel with an idealized symmetry reduces the amount of habitat complexity the river could form on its own. The ecological value of designed regular meanders may be higher than a previously degraded channel, but they are probably less valuable than restoration of the river processes of flow and sediment transport shaping the channel form. As Naiman et al. (1993, 211) wrote, "restoration efforts that consider disturbance regimes (frequency and intensity), hydraulic heterogeneity of the channel, and sediment dynamics, and that lessen human constraints on the channel, will be effective over the long term and at lower costs than engineering efforts directed at specified sites." The form-based restoration requires constraining the channel and limiting the ecological function. While it may have an aesthetic appeal and look more natural and ordered, it does not offer the richest habitat complexity.

The idea that a landscape can look more natural or reflect design with nature was the focus of chapter 3. McHarg (1969) and others portray 18th century English landscapes as examples of designing with nature and self-perpetuating. I found that although Capability Brown's riverscapes may look "natural", they survived the past two hundred years only because of significant human maintenance. I did not find evidence that Brown accounted for local sediment yield rates in his designs by adapting the design, nor did I find that dredging histories differed systematically with geology and geomorphology across England. Brown's water features are a visual but not functional imitation of nature, specifically lakes and river bends, on a grand scale. It may be that scale and variety are more important in explaining the appeal of the riverscape and its supposed natural qualities. Burt Litton (1974) described unity and variety as some of the most important aesthetic components of water landscapes. The scale of Brown's serpentine lakes is expansive possibly inspired by the famous view of the Thames River from Richmond Hill or possibly simply putting into the landscape a feature that is impressively large, makes water appear abundant, and frames the estate house and long open grassy lawns giving them unity. The abundance of water in a large lake implied wealth and contrasted with the typical English fluvial landscape dominated by small streams that would otherwise be only subtle features in the landscape.

The large lakes made by Capability Brown create lentic ecologies in historically lotic systems and represent a new ecology. Environmental management efforts aimed at protecting these new hybrid ecologies allow sections of riparian vegetation to grow while others continue to have open views and trim grassy streambanks. The streambank is a rich eco-zone where aquatic insects, amphibians, and birds spend all or part of their lives. Some lake managers incorporate vegetation or modify their maintenance of vegetation to allow the richness of this zone along Brown's water features to exist, instead of having a clean edge with mowed grass all the way to the water. Given contemporary interest in managing the lakes for habitat, current management regimes require consideration of both historic preservation of iconic elements of the English landscape and ecological conservation values.

Forman (2002) recommended planners and designers should attempt to mimic the forms of nature to decrease maintenance and cost. This is a form-based approach that favors curved lines and irregularity as natural forms and traditional human-made straight lines and regularity as unnatural forms (Forman 2002). My results show that even curved forms such as Capability Brown's riverscapes built in the eighteenth century in England, do not represent ecological design or design with nature. Further, the curves in river restoration may look natural and beautiful but are not the forms that the river would take in the absence of human design. In chapter 4 I described how the Cheonggyecheon restoration in Seoul, South Korea accomplished some level of ecological improvement from an underground pipe, but that the planning and design was geared towards making a human amenity. The short project timeline and political driving forces behind the river project lead to a fountain design where the water is pumped up from a different stream to the Cheonggyecheon location. The flow level is constant and provides the aesthetic illusion of a natural stream albeit with a strong cultural narrative. The existing infrastructure and population density clearly limited the restoration of dynamic river processes, but opportunities to bring nature back into the city could have been more holistic. The project may have been a first step towards building a culture of nature, but the form of the design is just a form not a restoration of river process or ecological function.

Landscape ecology deals with patterns and forms on a large landscape scale, yet the lessons learned in chapters 2-4 about aesthetic-ecological conflicts provide insight for ecological planning. The ideal landscapes promoted as design with nature need to be rethought, going beyond a curving or irregular form, to recognizing the abiotic processes determining river forms. Only protecting riparian corridors alongside a stream (indispensable patterns described in Forman 2002) as a solution to landscape ecological planning does not address the stream processes that might scour the riparian vegetation with large flows and shift the channel position over time creating dynamic habitats that change over time. A more sustainable multifunctional approach to river restoration would be to restore the physical river processes wherever possible (Beechie 2010, Wohl et al. 2005, Kondolf et al. 2001). An issue with waiting for the river to do the work of shaping its own channel form is the long amount of time that may be required, in contrast with shorter human project timelines and the expectation that the river should look more "natural" after restoration work. It may take longer than the amount of time project managers and stakeholders are willing to wait and the river may never produce an idealized symmetrical meander channel pattern.

7.3 Recreation-ecology conflicts

In chapter 4, the South Platte greenway represents a new river ecosystem state designed by humans as a recreational amenity with an underlying main function for flood conveyance. Restoring channel forming processes was not a priority and the project had low ecological success relative to the Cheonggyecheon and Isar River. Perhaps this is because the project emerged in the 1970s when greenways focused on recreation, as opposed to the multifunctional ideal being promoted today. The Confluence Whitewater Park, an element in the South Platte Greenway, was one of the first artificial whitewater designs built to improve the safety of boat passage around a dam. In chapter 5, I discussed the history of artificial whitewater moving from early Olympic designs and public parks such as Confluence through to the recent emergence of commercial recirculating courses. Due to the desire for a fair playing field for competition and the fact that the 2000 Sydney Olympic Games had no nearby whitewater river, designs for recirculating courses with no connection to a stream developed. The four most recent Olympic courses only mimic the whitewater and the larger river landscape is irrelevant to the experience. These designs allowed for greater control over the flow, obstacles, and viewing of the whitewater slalom races. The recirculating whitewater courses appear to provide no ecological stream benefits. The trend towards increased artificiality shifts potentially shifts paddler's attention away from natural streams and may impact the preservation of Wild and Scenic Rivers and other efforts to protect wilderness streams for recreation. Who is using artificial whitewater parks and how they view these in relation to wilderness rivers deserves further study. The history of artificial whitewater fits within the trend of outdoor sports moving to indoor urban constructed places where the risky elements of the outdoors are reduced and where the social mingling and movement is more important than connecting with nature or experiencing risk.

In the US, the artificial whitewater designs are mainly urban parks with freestyle surfing waves. A few of these parks in Colorado established recreational in channel diversions to maximize the functionality of the designs and recreational potential of the waves, but which were out of synch with the natural flow regime. These elevated summer flows for kayakers may exclude other instream park users and patterns of whitewater park use was the focus of Chapter 6. No change in the streamflow over a summer from May-August masks any seasonal difference that would occur when snow melts in Colorado and Nevada and flows go from high in May to low in August with the dwindling snowpack. Even when the flow release is limited to an 8AM-8PM timeframe on summer weekends, the pulse release does not fit with the natural flow regime and may have adverse ecological impacts as shown in past studies (Kupferberg *et al*. 2008). This guarantees functionality of the drop structure for kayaking, but does not provide ecological function and probably limits the diversity of instream users. Recreational streamflow releases may negatively impact aquatic species adapted to a snowmelt flow regime, as shown in past studies on pulse release flows for recreation (Kupferberg *et al*. 2008).

Chapter 6 addressed the extent and nature of whitewater park use, the physical factors influencing use, and user's perceptions of the park. Whitewater parks were originally conceived as river enhancements for kayaking, but became important for a more diverse, non-whitewater user group consisting of mostly non-specialized recreational users on the streambank. The parks clearly provide social benefits: urban residents can cool down on hot summer days, be physically active, and connect with streams in the city. Past economic studies asserted that streamflow affected kayaker use and in turn, the economic benefit of the park. However, I found the most important factor determining daily park use is the air temperature, not the streamflow. As it gets hotter more people visit, and as the water temperature warms up more people get into the river, particularly children. The perception questions posed to whitewater park users in a survey addressed what man-made and natural features they valued. Whitewater park visitors' valued clean water as the most important across all six parks studied. They did not mind seeing concrete in the river, they valued the artificial whitewater waves above fish habitat and shade along the riverbank (riparian vegetation), and they preferred a medium water level in the river, which may all limit the ecological potential.

The disconnection between the public's aesthetic preference and recreational use of the river and the ecological function is significant because creating multifunctional parks is the goal for most whitewater parks. As described in the history of artificial whitewater in Chapter 5, the trend is toward multifunctionality in instream whitewater parks, but aesthetics and recreational use still dominate the planning and design. In the future, careful site selection with good access, streamflow management for ecological and diverse human use, and more nuanced streambank design can encourage park visitation and improve the ecological design. Recognizing urban rivers as a commons can be increasingly beneficial as temperatures rise and people seek out places to escape the heat. Future study could evaluate trends in river park use over time in relation to temperature by repeating annual observations.

Observation studies are limited to one point in time and further study of whitewater park use could include observations earlier in the morning and later in the evening, during cloudy days, or during other seasons to acquire additional information on park use patterns. Future study could also compare how the use levels and patterns in whitewater parks compare to other urban, streamside parks that do not have artificial whitewater. One way to accomplish this would be to conduct surveys or observational data above and below the whitewater parks. This would also help to determine if the presence of boaters and tubers impacted the types and levels of other instream and streambank activities. Finally, additional studies on instream use as it relates to streamflow and water temperature for non-specialized uses (not requiring gear) could improve park planning and environmental management of urban streams. For example, would recreation streamflow provisions impact children's spontaneous use of streams (Kondolf and Yang 2008), since medium flow levels may result in higher near-bank velocities and thus make streambank edges less appealing for children?

7.4 Aesthetic-recreation-ecology synergy

In chapter 4 the Isar River project illustrated how aesthetic preference can align with ecological restoration. This was a fortunate coincidence. The choice of the Flaucher as the leitbild probably made the project more acceptable to the public because it was already a valued place for recreating and the only location where bonfires were allowed. Fortunately, it also embodied ecological restoration goals of a dynamic river corridor. The guiding image was not copied across the project reach, but rather informed the geomorphic and hydrologic design.

The key in this example is the braided river shapes its own dimensions wherever possible. Instead of defining the stream path and armoring it, the Isar River changes form within the limits of existing infrastructure. The planners and designers provided the river elbowroom and managed streamflow with a dam upstream to meet the needs of both ecological flow regimes and water supply (Kondolf 2012). They added sediment to the Isar River to supplement the loss of sediment behind dams.

The dynamic guiding image used in the Isar project allowed for a stream that changes its course over time, and as it adjusts, scientists and managers monitor the changes and adapt the plan. Measures still exits along the stream to protect urban infrastructure, but less so than on the South Platte and Cheonggyecheon. The design for the Isar, unlike the Cheonggyecheon and South Platte does not conform to typical aesthetic preferences for a river as described in past studies. Linking river perceptions with ecologically sound planning and design may encourage a shift in people’s understanding of the ecology within cities. Planners saw actions taken to improve the ecology, such as increasing the gravel banks, as a way to also improve the recreational opportunities.

In a similar way, instream whitewater designs have recently integrated in environmental considerations for habitat improvement alongside recreation and aesthetic improvements. Designs built into streams have had to integrate in fish passage and other environmental considerations, usually in the same cross-section of the stream designed for recreation. More sophisticated two-dimensional modeling to predict fish passage at the wave structures has been conducted. One design approach to fish passage at a whitewater drop is to create slower velocity on the edges of the drops and interstitial space for flow in the drop.

7.5 When to use a multifunctional planning and design approach

How the cultural and ecological values manifest themselves in riverscapes is a reflection of social priorities. In cities, the focus on culture often outweighs the ecology, yet recent trends in restoration, ecological design, and planning for green infrastructure suggest this is changing. This change in riverscape planning and design will improve the sustainability of cities, the places where the majority of people live today. As urban stream planning and design progresses there is a need to monitor the results to improve the multifunctionality or separate functions when they are found to be completely incompatible. It is too much to expect multifunctional riverscapes to accomplish win–win solutions in all contexts. There are many situations where it is simply not possible to compromise between conflicting interests: either one interest wins or the other. A compromise may result in neither winning.

Multifunctionality works in cities, but should not be a strategy for all riverscapes. For example, rivers in national parks and designated wilderness rivers should be protected and multifunctionality may represent a threat to preservation. In these cases, monofunctionality focused on river protection may be appropriate. Similarly, in river restoration projects where there are no constraints on letting the channel define its own path and shift location within the floodplain, then monofunctionality geared towards ecological restoration may be appropriate. In these cases the aesthetic appreciation and recreational use may occur at the restoration sites, but they are not planned or designed for. They can arise spontaneously and in response to the opportunities of the site. Investing money in river restoration in cities makes sense since these are the places where the most impacts have occurred and where people are in contact with the river and water.

This is not to say that restoration of wilderness rivers should not occur, but that they may be able to restore themselves given enough time, if the underlying processes are intact. Landscapes can be purely naturally produced and these should not be planned and designed based on a multifunctional approach. In these undeveloped landscapes the river processes function in some degree of isolation and provide a counter example to a planned and designed landscape. The multifunctional approach is best suited to developed places where rivers are the product of people and 'nature', or cultural riverscapes. Restoration of a specific channel form does not meet the needs of multifunctionality and a passive approach to restoring flow and sediment processes over a long time scale may be more sustainable.

Another example where monofunctionality may be preferred is historical preservation, as in Capability Brown's lakes, where the emphasis on multifunctionality compromises the historical aesthetic. In some cases, the social values associated with a specific design may outweigh multifunctional goals. The cost of maintaining these landscapes should be conceptualized not only in the current time but also in the time and situation in which the landscape was built. In Capability Brown's time the concentration of wealth in estates held by a few lead to the landscape designs. The control over small streams to create large lakes sometimes came at the expense of inundating a town. The designs required massive investments to make and maintain these monofunctional landscapes. From a sustainability point of view, these landscapes do not balance equity along with economics and environment.

Multifunctionality developed out of Europe and the UK where the landscape has been developed for a long time and where few unplanned and un-designed areas exist. Multifunctionality is associated with the idea of sustainable development and green infrastructure. It is different than multiple-use in that multifunctionality "involves more than mere 'layering'" (Selman 2009). Some contend multifunctionality is eco-centric; however, I would say the opposite that integrating social and ecological functions is inherently anthropocentric and defined based on cultural values. Where multifunctional riverscapes are successful they reconnect social and ecological functions, allow physical processes to behave without major human intervention or maintenance, and provide ways for people to enjoy and have a better quality of life based on the particularities of the place. Multifunctionality can lead to more sustainable development rather than continuing to attempt to control physical processes for human benefit. It lends itself to a care versus control mentality and to letting go and accepting a degree of risk in river planning and design (Selman 2009, Nassauer 1997).

As Lawrence Halprin, a landscape architect who designed urban water features said, "There is real danger, however, of losing sight of the inherent quality of water in these exuberant amusements—of that very quality of chance which water brings to us. When we control too much, we have lost the great virtues of unpredictability and have made instead a static form out of a wild and noble element" (1963:135). The challenge is how to plan and design to promote complex dynamic river processes along with aesthetics and recreational use.

7.6 Multifunctionality, sustainable development, and design with nature

This research illuminates some of the aesthetic-ecology and recreation-ecology conflicts in multifunctional riverscapes, but is only a first step. The research builds on past multifunctional studies and integrates the fields of landscape architecture and landscape ecology in a trans-disciplinary approach. Challenges remain to bridge landscape ecology planning with planning that includes cultural and aesthetic values. The aesthetic values may conflict with the ecological function, and design solutions may provide some solutions. However, another issue that needs attention is refining our understanding of design with nature and moving beyond historical ideals, specifically 18th century English landscape aesthetics. Planners and designers should recognize that the ecological function of 18th century English landscapes represents a new hybrid ecosystem not the spontaneous stream processes that would occur in the absence dams. New riverscapes such as the Isar River project can present people with a new sustainability aesthetic. These new riverscapes may challenge cultural conceptions of what is natural. In all cases, the riverscape designs should allow contact with the water when the water quality is safe.

There are many different definitions for ecological function; I defined ecological function as the physical conditions and processes that sustain biological communities. Ecological function can also be defined as the "services" that ecosystems provide, such as moderating climatic extremes, reducing waste, and purifying air and water. How ecological function is defined shapes whether it takes a more human centric or eco centric approach. Landscape ecology addresses aerial views of landscapes, designating multiple uses or identifying habitat patches and landscape processes. In contrast, the success of river restoration projects or the health of the landscape is often judged from a ground-level perspective. Integrating landscape ecological planning with local-level understanding of the patterns of human use and perceptions of landscapes in relation to biophysical processes is fundamental to sustainability. These two levels of planning, aerial view and ground level should work together to create multifunctional landscapes, otherwise the aerial interpretation will not match the ground level reality and vice versa.

The increasing urban population is one of the most important social and ecological challenges to our sustainable future. Landscape architects and ecologists already recognize rivers as providing significant human and habitat value. Further, society is investing in improvements to river corridors and water quality to create additional habitat and water access. Multifunctional riverscapes provide a key resource for sustainable development. Riverscapes can be planned in a way that enables the fluvial geomorphic processes wherever possible, which will lead to improved habitat and less maintenance. Instead of focusing on form, planners and designers can address the underlying physical and biological functions and serve a broad range of constituents, human and otherwise. Fostering awareness and appreciation of river dynamism should be a goal in all river projects and allowing people to connect with the river can motivate them to care for it. It is essential to involve a broad range of people in river planning so riverscapes do not tailor to a special interest group. A pitfall in multifunctional riverscape planning and design would be losing sight of the underlying processes that provide habitat and a diversity of human use and instead creating synthetic riverscapes for leisure and consumption with only a green trim. We are in the era of restoration and designed ecosystems and we need further study to evaluate the effectiveness of existing projects and understand the tensions between cultural values and ecological functions to advance sustainable development.

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Table 10. Matrix of research chapters and their individual focus, results, and whether the results present conflicts or synergy with the ideal of multifunctionality.

Chapter	**Chapter 2** **Ideal s-curve**	**Chapter 3** **Design with nature and persistence**	**Chapter 4** **A river or a fountain?**	**Chapter 5** **History of artificial whitewater**	**Chapter 6** **Whitewater use, values, and streamflow**
Riverscape Type	River restoration, artificial lakes	Artificial lakes	River restoration, recreation design	Recreation design	Recreation design
Functions	Aesthetics (*elements of beauty*) + Ecology	Aesthetics (*what looks natural*) + Ecology	Aesthetics (*what looks natural and elements of beauty*), Recreation + Ecology	Recreation + Ecology	Recreation + Ecology
Main Result	Symmetry appears in river restoration designs.	Brown's designs not design with nature and require long-term maintenance	Cultural values and constraints/ planning determine ecological value	Artificial whitewater separated from streams, instream designs incorporate habitat	Human use concentrated on banks and kayaker use not related to streamflow, users' values
Conflict or Synergy Between Functions?	Conflict	Conflict	Both	Both	Both