Developing An Ecological Sanitation Transect

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DEVELOPING AN ECOLOGICAL SANITATION TRANSECT

A Thesis Presented

By

IAN JAMES KOLESINSKAS

Submitted to the Graduate School of the University of Massachusetts Amherst in partial fulfillment of the requirements for the degree of

MASTER OF REGIONAL PLANNING

February 2016

Master of Regional Planning Program
DEVELOPING AN ECOLOGICAL SANITATION TRANSECT

A Thesis Presented

By

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Landscape Architecture and Regional Planning
DEDICATION

For my grandmother, Audrey Schurmann. Rest in peace.
ACKNOWLEDGEMENTS

I would like to thank my committee chair, Robert Ryan, for his guidance and interest in my research. Thank you to Wayne Feiden for being a member of my committee as well as a planner to look up to. Mark Hamin, thank you for being my advisor and mentor during my time in the MRP program and for recruiting me into Environmental Design in the first place.

I want to thank Elisabeth Hamin for running a fantastic department. Thank you to all the MRPs, PhDs, and MLAs that I got to know so well at UMass. You opened my mind and really taught me the meaning of hard work.

A special thank you to Traci Laichter for supporting me and my loving family for always encouraging me.
ABSTRACT

DEVELOPING AN ECOLOGICAL SANITATION TRANSECT

FEBRUARY 2016

IAN JAMES KOLESINSKAS, B.S., UNIVERSITY OF MASSACHUSETTS AMHERST

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Directed by: Robert Ryan

A sanitation problem exists for people across the globe: basic human waste collection and treatment is inaccessible to much of the world’s population; and the status-quo gray infrastructure system of sanitation is unsustainable and unsuitable for widespread application. A paradigm shift is needed: this thesis makes the case for developing an Ecological Sanitation Transect to bring back the closed loop that connects consumption, waste excretion, sanitation, and food production. The Ecological Sanitation Transect is a synthesis of ecological sanitation, where human excreta is reused, and the urban transect, where development density is conceptualized along a continuum from rural to urban. Current literature related to transects, sanitation, and the links between them is investigated. An analytical overlay of ecological sanitation strategies onto the transect framework with accompanying visualizations is the resulting integration of these ideas. Case studies from across the transect are detailed. A concluding discussion is followed by directions for future research.
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CHAPTER 1

INTRODUCTION

This work is intended to help the reader implement ecological sanitation in their community by adapting the transect framework to catalogue and define contextually appropriate ecological sanitation strategies. First, background information on the sanitation problem is introduced: how modern sanitation came to cities in the developed world while basic sanitation is still inaccessible to a large segment of the world’s population; and how the system of water-based conveyance sanitation (as promoted in the developed world) is unsustainable and unsuitable for widespread application. Next, current literature related to transects, sanitation, planning regulation and the links between them is examined, as well as areas warranting further research. Then, research questions are posed and methodologies for conducting the research are explained. This is followed by an illustrated catalogue of ecological sanitation strategies linked to transect zones along with case studies of implemented systems. Finally, an analysis and interpretation of the results is presented. Figures referenced in the text are found in the body of the thesis and references appear at the end of the document.

1.1 A Brief History of Sanitation

Most of the developed world’s population lives in an environment where proper sanitation is widespread. Here one finds conveniences such as clean
running water for cooking, cleaning, and bathing as well as safe and comfortable places to relieve oneself of urine and feces.

The rapid industrialization and urbanization of the 19th Century quickly taught cities that their historic sources of water such as springs and wells (and aqueducts in ancient cities) were inadequate to serve burgeoning populations. Surface waters from lakes and rivers had to be formally harnessed and brought to city dwellers through systems of pipes and aqueducts (Blake 1956, 2). With increased municipal and private investment came broader availability and consumption of running water and the ability to remove waste at the domestic scale and beyond (Benidickson 2007, 77). At first, human excreta, industrial waste, and other urban detritus were simply piped into moving water bodies, often the same ones from which ‘fresh’ water was being collected. However the emerging understanding of contagion and disease transmission led to some grave realizations. In 1854 physician John Snow studied a cholera outbreak in Soho, London, mapping victims and survivors and ultimately concluding that those infected had consumed water from a specific pipe (or closely knew someone who had). This was linked to other research on death rates in areas served by private water companies in-taking from the Thames River, showing how upstream service was less deadly than water collected downstream (Benidickson, ix). The public health implications were enormous, and cities began taking precautions to safeguard their water supplies from sewage as well as introducing testing, filtration, and treatment (Blake, 260-263).
1.2 The Problem

Each year over 2000 million metric tons of human waste goes untreated (Haq and Cambridge 2012, 41). The potential health risks associated with exposure to this waste are enormous: bacteria, parasites, and viral infection leading to diarrhea, malnutrition, and death. Water–borne conveyance sanitation promises to ameliorate these problems by piping human waste away from where it is produced and then treating it. The problem arises from the reality of this system, where 90% of the world’s wastewater is either discharged straightaway or is unsatisfactorily purified (Werner et al. 2009, 393).

The water based conveyance approach to sanitation is unsustainable in part because it is built as gray infrastructure. Gray infrastructure includes human-made channels, sewer systems, storm drains, water mains, water treatment facilities, curbs, gutters, downspouts, and pavement. The overarching concept behind gray infrastructure is conveyance: channeling and directing water away from a site to be dealt with elsewhere. One disadvantage of gray infrastructure is that the pervasive use of concrete and pavement creates large areas of impervious surface that prevent the natural infiltration of water. This means that as rainwater flows over pavement it picks up pollutants including sediment, bacteria, heavy metals, hydrocarbons, and nutrients and can then contaminate ground and surface waters (Madden 2010, 16).

Another limitation of gray infrastructure directly related to sanitation arises from the wide use of combined sewer systems. A combined sewer system
channels storm water and human waste into one flow that is sent to a treatment facility before being discharged into a water body (US EPA 2011). Combined sewer overflow (CSO) occurs when a storm event deposits more water into a combined sewer system than can be treated at one time. The result is an evacuation of the flow (storm water and raw sewage) directly into the water body. The United States Environmental Protection Agency recognizes that this has negative effects on the ecology of the water body as well as potential human health impacts from exposure to the untreated sewage (US EPA 2012).

Developing nations that lack the funding and centralized resources to build the large-scale wastewater treatment plants required for sewer systems instead rely on dry methods such as latrines, cesspits, and other family or neighborhood scale solutions. This uncoordinated, piecemeal approach can result in pollution of groundwater as well as contamination of potable water (Haq and Cambridge, 2012). For many rapidly urbanizing nations, water is a precious resource and chronic scarcity can impede development and negatively impact human health (Faruqui and Al-Jayyousi, 2002).

Clearly an alternative to gray infrastructure-based, water-borne sanitation is needed. Both developed areas with established systems and developing areas seek to answer questions such as what do we do with our excrement? How do we treat it? How do we pay for that treatment? How do we preserve our water supplies? How do we feed a growing population? How do the answers to these questions differ between rural, suburban, and urban areas?
1.3 A Solution

Enter ecological sanitation, which differs from the conventional gray infrastructure approach to sanitation primarily because of the way it views human excreta. The conventional approach looks at urine and feces as waste products to be transported away from the producer and disposed of; someone else’s business. They are collected together, conveyed by water, and treated to get rid of nutrients and pathogens. The cleaned up liquid is then discharged into a waterbody. Issues such as CSO, water management concerns, nutrient pollution, and affordability all lend criticisms to this system, however. Ecological sanitation provides an alternative view of human excreta as a resource containing nutrients that are vital to agriculture. Urine, feces, stormwater, agricultural, and organic ‘waste’ are collected separately at the point of production and processed to remove pathogens. The resulting graywater and humanure (human + manure) can then be applied to plants as irrigation and fertilizer (Winblad et al. 2004, 4).

Because ecological sanitation is not a prescriptive suite of technologies, but rather a concept or philosophy of waste and sanitation, there are many approaches in carrying it out. The research proposed in this work seeks to aid urban and regional planners as well as interested stakeholders in selecting and implementing ecological sanitation systems in their communities.

To carry out that task across a region, an organizational tool is needed. The transect concept offers a framework for visualizing and cataloging the various ecological sanitation methods across a continuum of natural and human
derived variables. A transect is a geographical cross-section of a selected environment, originally used in ecology to identify the habitats in which certain plants and animals thrive. From this origin the transect idea has been adapted by planners, urbanists, landscape architects, and others as a powerful tool for comparing elements of the natural environment as they interface with human systems across varying topographic zones. As is the case in this proposal, visualizations of transects are often linked to a descriptive, analytical assessment of the zones and proposed interventions. Relevant case studies for communities have been assembled as part of this work in an effort to inform the reader about real-world applications of ecological sanitation in the United States.
CHAPTER 2

LITERATURE REVIEW

The current literature on transects, sanitation, and planning regulation displays a rich spread of theory and practice. In this section transects are introduced through a brief history and then urban and green infrastructure transects are more closely examined. Next conventional sanitation technologies are described along with some of the limits to those systems. The concept of ecological sanitation is explored through articles pertaining to both the overarching paradigm as well as specific applications of ecological sanitation and their benefits in comparison to gray infrastructure. Planning regulation as it relates to sanitation and the Urban Transect rounds out the literature review. Then areas of overlap between the subjects are identified as well as gaps in the literature that illuminate opportunities for further research.

2.1 The Transect In Planning

The ecological transect is a geographical cross-section of a selected environment used to identify the habitats in which certain plant and animal communities thrive. Conceived in the field of ecology, the transect has been used as a conceptual and analytical tool as early as the 18th century (Duany Plater-Zyberk & Company, 2014). The power of the concept comes from its ability to show many detailed contextual environments in situ while simply and comprehensibly allowing for comparisons and contrasts to be made between them.
The idea of the transect has been adapted by planners for a number of purposes. In 1909 Scottish urbanist Patrick Geddes illustrated the Valley Section [Figure 1].

The diagram is a longitudinal section view beginning in the mountains and moving downhill through forest, pasture, plain, shore, and to the sea. Along this section Geddes noted occupations he believed to be best adapted to that environment. The Section is significant in the way that it ties natural topography to human conceptions of land-use (Welter 2001, 90-91).

Further evolution of the idea came from Leberecht Migge, a landscape architect who was active in pre- and post-World War I Germany. Migge put much thought into preserving and promoting the connection between people and the environment. His work combined ideas from organic gardening, architecture, and biology in what can be described as green modernism (Haney 2010, 1). Featured
prominently among his designs was the desire to unite natural and man-made systems, a theory known as biotechnic. Migge’s designs sought to integrate the house, garden, and inhabitant by growing vegetables for consumption and using household waste, including human excrement, as fertilizer in order to maintain a self-sufficient cycle. During this time many urban areas were considering the implementation of water-based sewerage systems. In order to preserve the nutrients found in excrement, Migge advocated for the use of dry toilets and composting silos rather than flush toilets that would negate the possibility of reuse (Hanley 2010, 107-109).

Figure 2: The Growing Siedlung. Leberecht Migge. 1932

In 1932 Migge published Die wachsende Siedlung (The Growing Siedlung), part of his ongoing work with housing settlements. The idea here was
to create housing that would grow with a family: a couple would move into the basic dwelling and then the unit could be added onto and garden plots expanded as children were born [Figure 2]. Although the idea for this settlement was not necessarily along the same line as the transect, Migge envisioned the family as the agent of growth and the settlement as the scale of planning. His resulting diagram of the phases of growth illustrated adjacently bears a striking resemblance to Andrés Duany’s Urban Transect [Figure 3].

![Figure 3: Urban Transect. Andrés Duany. 2008](image)

New Urbanist planner Andrés Duany adopted the transect around 2000 to create his Urban Transect [Figure 3]. This tool draws out a spectrum of human habitation that varies by the intensity of natural and built environment. Duany states:

“The Transect works by allocating elements that make up the human habitat to appropriate geographic locations. For example, human habitats that are rural might consist of wide streets and open swales. Human habitats that are more urban will likely consist of multi-story buildings and public squares. Accordingly, wide streets and open swales should be allocated to more rural zones whereas multi-story buildings and public squares should be allocated to more urban zones.”

(Center For Applied Transect Studies 2014)
The Urban Transect is applied in order to ameliorate the inappropriate intermixing of rural and urban elements and is tied to the SmartCode, a form-based code that uses Smart Growth and New Urbanism principles to create a model ordinance framework (Duany and Talen 2002, 247). The framework is meant to address varying scales of development, from regional planning to setbacks and building signage.

2.2 Adapting the Urban Transect

More recently, planning and design firm Duany Plater-Zyberk & Company (DPZ) has further adapted the Urban Transect in its conceptualization of Agrarian Urbanism. DPZ describes Agrarian Urbanism as assimilating agriculture into a modern, urban life while allowing for the walkability, compactness, and other benefits associated with transect planning. This integration ensures food security and a strong local economy as well as fostering community (Duany, Plater-Zyberk & Company, 2014). The Agrarian Urbanism Transect’s combination of subsistence farming with varying density of development shows how the Urban Transect can serve as a framework for incorporating other ideas [Figure 4].

Similarly, Stephens Planning & Design has modified the Urban Transect into the Agri-Urban Spectrum, which ties permaculture concepts to the density/intensity of land use associated with the urban-rural continuum [Figure 5].
Figure 4: Agrarian Urbanism Transect. Duany Plater-Zyberk & Company. 2009

Figure 5: Agri-Urban Spectrum. Stephens Planning & Design. 2011
2.2.1 Green Infrastructure Transects

The ecological and urban transects have been synthesized by Yaser Abunnasr and Elizabeth Hamin in their Green Infrastructure Transect [Figure 6 and Figure 7]. Similar to the relationship between Duany’s Urban Transect and The SmartCode, Abunnasr and Hamin’s approach to green infrastructure planning takes into account both the transect segments (coastal, urban core, urban, transition, suburban, and peri-urban) and criteria for assessing the green infrastructure interventions for each zone: vulnerability assessment using spatial data (physical and social), identification of primary climate change impact based on spatial configuration and character, identification of the spatial character of each GI zone, determination of the spatial configuration of pervious and impervious surfaces (including existing and potential GI), determination of GI typology relevant to each zone, and recommendation for appropriate GI measures within each zone (Abunnasr and Hamin 2012, 205-217).

The Green Infrastructure Transect is used to simultaneous consider human and natural systems as mutual cause-and-effect relationships affecting the functional capability of GI, designate transect zones as uniquely contextual in their adaptive capacity, and to explicitly consider GI as an interconnected system that transcends administrative and political boundaries. This Green Infrastructure Transect takes into account both visual/spatial/geographic elements and theoretical/political/descriptive aspects in its execution.
Figure 6: Identification of GI Policies. Abunnasr and Hamin. 2012

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Figure 7: Horizontal & Vertical Integration. Abunnasr and Hamin. 2012

- Natural defenses
- Surge reduction
- Recreation
- Planned Retreat
- Densify coastal GI
- Protect Coast
Figure 8: Green Infrastructure Transect. AECOM Design + Planning. 2010
Another Green Infrastructure Transect also exists. Created by AECOM Design + Planning for their ASLA award-winning Kigali Conceptual Master Plan, this version illustrates land use/building type and density, topography, and green infrastructure interventions [Figure 8]. The plan for Rwanda’s capital city takes into account urbanization’s influence on future land uses and density, and how this relates to local topography. The transect model allows for the design of mixed-use development and the locating of various land use classifications into manageable development zones (American Society of Landscape Architects, 2010).

2.3 Sanitation Systems

The most common types of sanitation systems can be categorized broadly as latrine, septic, and sewer systems. Elizabeth Tilley, Lukas Ulrich, Christoph Lüthi, Philippe Reymond, and Christian Zurbrügg’s *Compendium of Sanitation Systems and Technologies* provides one of the most comprehensive collections.

2.3.1 Latrines

Latrines, pit toilets, and privies refer to toilet systems where urine and feces are collected and held in a vault or pit beneath a toilet. Once a certain level of material has accumulated it must be removed and either treated off-site or sent to a landfill. These systems do not typically involve flushing or water conveyance. The storage of raw excreta, where pathogens are likely present, raises a concern for this type of sanitation system. There is a risk for those extracting the stored
material and for the possibility of pathogens and nutrients to leach out of the pit into surrounding soil and groundwater (Tilley et al 2014, 21).

2.3.2 Septic Systems

In this system flush toilets, sinks, and showers convey excreta and graywater a short distance away from a dwelling and into a septic tank. The tank is designed to prevent solids from leaving while the effluent is distributed into leachfield. Here a series of perforated pipes allow the liquid to drain slowly through gravel beds and into the soil below. As the system comes online and begins spreading this leachate, a colony of aerobic microorganisms forms which serves to eliminate most pathogens and reduce nutrients levels (Feiden and Winkler 2006, 11-13). Despite the ability for onsite treatment, these systems still require periodic pumping to remove sludge, the buildup of greases and excrement solids in the septic tank. In order to function properly septic systems require a constant source of water ad well as proper siting in suitable soils that allow for the right amount of drainage (Tilley et al 2014, 31). An improperly functioning system may go unnoticed, as the components are underground, resulting in groundwater pollution.

2.3.3 Sewer

Sewer systems may be the most familiar type of wastewater treatment in the United States. In this system flush toilets send excreta and graywater away from a dwelling and into a common series of pipes or channels (sewer main) leading to a centralized treatment facility. This system also requires a constant
flow of water to properly function. The main disadvantage of this system is its great expense and the extensive infrastructure network required. When sewer systems are designed to collect stormwater in addition to excreta and graywater there is a risk of CSO (Tilley et al 2014, 35).

Each of these conventional sanitation systems views excreta as a waste product produced by humans and then disposed of in a linear fashion. The nutrients held by the excreta are not collected or utilized in any meaningful way but are instead diluted with clean water (in the case of flush systems) which is then treated to remove them in order to make that water clean again.

2.3.4 Biosolids

Conventional sanitation does present one example of the reuse of human excreta. The EPA defines Biosolids as “nutrient-rich organic materials resulting from the treatment of domestic sewage in a treatment facility” (US EPA 1994). Biosolids are used as fertilizer for gardening and agriculture. Biosolids are considered part of conventional sanitation in this work because they are a result of the conventional water conveyance system. One concern in the use of biosolids as fertilizer is that sewer sludge not only contains pathogens, but also can contain heavy metals and chemicals resulting from improper disposal down drains. If EPA guidelines are followed for monitoring of pathogens and trace contaminants the risk to human and environmental health is low (US EPA 1994).
2.5 Ecological Sanitation

Ecological sanitation, or ecosan, is an alternative to the current conventional approach to sanitation. Ecological sanitation is based on a view of sanitation as part of an ecologically and economically sustainable wastewater management system, which can be tailored to fit specific user and location contexts. It is not a specific technology, but represents a new way of conceptualizing waste management as a cycle or feedback loop, rather than the current linear approach. Ecological sanitation is an attempt to create a sustainable sanitation system by using an ecosystem and resource management perspective (Werner et al. 2009, 394).

Ecological sanitation differs from the conventional approach to sanitation primarily because of the way it views human excreta. The conventional approach looks at urine and feces as waste products to be disposed of. They are collected together in water-borne plumbing and (in theory) treated to acceptable levels of nutrients and pathogens before being released into a water body or into the ground through leaching fields [Figure 9]. The problem arises from the reality of the system, where 90% of the world’s wastewater is either discharged straightaway or is unsatisfactorily purified (Werner et al. 2009, 393).

In contrast, the Ecological Sanitation approach can be characterized as ‘sanitize-and-recycle’. Unlike the conventional linear take on sanitation, ecological sanitation is a closed-loop system. It views human excreta as a resource containing nutrients that are vital to agriculture. Urine and feces are
stored and processed on site, or if necessary, further processed offsite to remove pathogens. The refined urine and remaining solid material, sometimes referred to as humanure (human + manure), can then be applied to agricultural or ornamental crops as a fertilizer (Winblad et al. 2004, 4) [Figure 10].

Figure 9: Conventional Sanitation. Werner et al. 2009
2.5.1 Collection

One of the theories of ecological sanitation is the separate collection of wastes and specialized treatment for each stream (urine, feces, organic/agricultural waste, and stormwater). Because Ecological Sanitation is not a prescriptive suite of technologies, but rather a concept or philosophy of waste and sanitation, there are many approaches in carrying it out. Composting and urine separating toilets are often utilized because they help to conserve potable
water and prevent pathogens from entering ground or surface water. When urine is diverted and kept separate from feces there is less odor, less exposure to pathogens, and less processing and treatment is required. Urine contains nitrogen, phosphorus, potassium, sulfur and other nutrients in forms that can readily be used by plants. Using urine as fertilizer has shown yields comparable to chemical fertilizer in crop production (Richert et al. 2012, 1-2).

2.5.2 Treatment

Wastewater Gardens are a particular application of ecological sanitation that use subsurface flow constructed wetlands to mimic the filtering ability of natural wetlands. The subsurface wetland is used because it keeps the wastewater level below the substrate surface, thus minimizing odors, precluding human contact, and preventing the proliferation of mosquitos and other disease vectors. It is also a low cost and low energy system that requires minimum maintenance (US EPA 1993, ii). Biogeochemical processes work to treat the wastewater, with plants living in water-saturated soil being one of the principal factors working to directly assimilate nutrients (especially nitrogen and phosphorus) and metals, removing them from the water and incorporating them into plant tissue. A symbiotic relationship between these plants and subsurface microbes sustains this process (Wastewater Gardens, 2014). The highly effective process reduces Biological Oxygen Demand by up to 95%, Total Suspended Solids by up to 95%, and nitrogen and phosphorous by up to 80% and 60% respectively. Especially significant to sanitation is the fact that these systems
have been shown to eliminate up to 98% of coliform bacteria (Wastewater Gardens 2014, “Water Treatment Levels”).

Wastewater Gardens are economically advantageous because although they may have the same or slightly higher initial investment and installation costs compared to conventional Sewage Treatment Plants, the operating and maintenance costs are typically 90-95% lower as well as having longer lifespans. Maintenance of Wastewater Gardens mostly consists of selective pruning and some dredging. The constructed wetland and secondary subsoil irrigation can be used to grow crops like timber and fiber, flowers, medicinal plants and herbs, and fruits and vegetables. Finally, Wastewater Gardens are constructed with local materials and labor, without the need to import machinery or chemicals (Wastewater Gardens 2014, “The Sound Economics of Wastewater Gardens”).

2.6 Ecological Sanitation and Density

In reviewing the current literature on ecological sanitation, building density and land use are frequently addressed as variables in designing or as constraints in implementing different collection, treatment, and application strategies.

In Magid et al.’s "Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas” there is a clear connection between the types of housing/density of development and the chosen system of ecological sanitation. The study defines six different built environments early on in which to apply its four types of waste handling systems (Magid et al. 2006, 45):
1) Dense urban center (building blocks in dense formation).
2) Open urban center (older houses 1–2 story in dense formation).
3) Flats with surrounding open spaces.
4) Chain houses (1–2 story, low density).
5) Villas (single houses with surrounding open space).
6) Allotments (small plots with shacks used in spare time for leisure and food production).

The four waste handling systems were developed by considering the various constraints associated with the given housing types. System 1 was chosen for housing in the center of the town, because there was not enough space for systems with separate urine or feces collection and it would have been difficult to collect urine with a truck on narrow streets. System 2 was designated for self-contained houses, row houses, flats, and houses on the rim of the town center because there was enough space for collecting tanks and local use of organic kitchen waste. System 3 was used in row houses and self-contained houses where it was possible to collect feces. Finally, System 4 was implemented in the allotment gardens as there was not an existing sewer system and the land area facilitated reuse of all the waste products locally (Magid et al. 2006, 46-49). Figure 11 shows which areas of the town were chosen for each system.
Land use is an important focus in Rockstroem et al.’s “Sustainable pathway to attain the Millennium Development Goals: Assessing the key role of water, energy and sanitation.” Here the rural-urban continuum is the primary frame into which a comparative economic assessment of ecological sanitation and traditional sanitation methods is placed. In the sanitation cost ladder eight types of sanitation methods are compared, with mostly urban, mostly peri-urban, and mostly rural as the main organizing element [Figure 12, next page].
<table>
<thead>
<tr>
<th>Method</th>
<th>Conventional Sanitation</th>
<th>Estimated cost per person (USD) incl. operation and maintenance</th>
<th>Ecological Sanitation</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewer connection and secondary wastewater treatment</td>
<td>800 (sourced from UN Millennium Project, 2005; original source UNEP, 2004)</td>
<td>340 (1190 per hh) (China, hh size 3.5) (source: Dong Sheng EcoSanRes Programme)</td>
<td>Urine-diverting high standard porcelain in dry toilet (indoor and multistory); piped urine system, dry faecal collection and composting, decentralised piped grey water treated using septic tank and aeration treatment; local collection and transportation costs included</td>
<td></td>
</tr>
<tr>
<td>Connection to conventional sewer (assumed without treatment)</td>
<td>450 (Sarawak) (estimated) (source: Mamit et al., 2005)</td>
<td>330 (1500 per hh) (China, hh size 3.5) (source: Dong Sheng EcoSanRes Programme)</td>
<td>Conventional indoor toilet with sealed conservancy tank, black water collection by truck; local biogas digester; decentralised piped greywater treated using septic tank and vertical biofilm filter technique</td>
<td></td>
</tr>
<tr>
<td>Sewer connection with local labour (assumed without treatment)</td>
<td>300 (South Africa) (source: Morgan, 2005)</td>
<td>175 (Mexico, El Salvador, India, South Africa, Zimbabwe) (source: Morgan, 2005)</td>
<td>Indoor dry single-vault urine-diverting pedestal toilet; decentralised piped greywater treatment using constructed wetland; local transportation included</td>
<td></td>
</tr>
<tr>
<td>Septic tank latrine</td>
<td>160 (South Africa) (source: Morgan, 2005)</td>
<td>12 (55 per hh) (source: Lin Jiang, Nanning, Guangzi, China)</td>
<td>Dry single- or double-vault urine diverting squatting pan or pedestal toilet with permanent upper housing structure; greywater treatment using on site infiltration pit; transportation assumed as local labour</td>
<td></td>
</tr>
<tr>
<td>Pour-flush latrine</td>
<td>70 (West Africa) (source: Khtse &amp; Ahlgren, 2005)</td>
<td>8 (35 per hh) (source: Morgan, 2005)</td>
<td>Dry single or double-vault urine diverting squatting pan or pedestal toilet (LASF or Skyloo) with permanent upper housing structure; greywater treatment and disposal onsite; local recycling</td>
<td></td>
</tr>
<tr>
<td>Improved traditional Practice</td>
<td>10 (estimated) (source: Morgan, 2005)</td>
<td>3 (10 per hh) (estimated)</td>
<td>Soil composting shallow open pit; soil added after each use</td>
<td></td>
</tr>
</tbody>
</table>

Figure 12: Assessing the Key Role of Water, Energy, and Sanitation. Rockstroem et al.
CHAPTER 3

DEVELOPING AN ECOLOGICAL SANITATION TRANSECT

The transect presents an interesting and effective tool for mapping and visualizing variables across ecologies. Planners, urbanists, landscape architects, and others have used it in a variety of ways. Because of the comprehensive nature of ecological sanitation, there are many different approaches and technologies that can be employed in order to effectively separate, treat, and reuse stormwater, organic waste, and human urine and feces. Reviewing the literature on these concepts reveals an exciting amount of overlap. Leberecht Migge designed and built settlements that utilized ecological sanitation methods, and certainly thought about family size and community scale in his Growing Siedlung concept. Abunnasr and Hamin’s Green Infrastructure Transect takes water regeneration and food production into account when prescribing green infrastructure solutions that utilize natural systems in order to mitigate the negative effects of gray infrastructure, in part. The Agrarian Urbanism Transect and Agri-Urban Spectrum address organic farming and gardening and the need to increase the intensity of food production as population density grows.

In order to bridge the gaps between these lines of thinking, I propose the development of an Ecological Sanitation Transect. This tool will combine elements from both Duany and Hamin/Abunnasr’s transects with closed loop nutrient cycling to provide density and land-use contextual examples of ecological sanitation.
As population increases and land-use changes across the rural-urban continuum, different types of ecological sanitation practices and technologies will be appropriate. Climate could also be an influencing factor, as constructed ecological systems must be engineered to tolerate varying temperature and weather patterns. Sanitation is everyone’s business, and shifting the paradigm away from expensive, energy-intensive gray infrastructure systems towards lower cost, more resilient ecological systems is a demonstrated way of working towards meeting the Millennium Development Goals and creating a more sustainable society.
CHAPTER 4
RESEARCH QUESTIONS

*How can a framework of ecological sanitation practices and technologies be created for communities in varying contexts?*

**Claim:** the transect, as utilized by planners, landscape architects, and others in related fields, offers a conceptual and organizational framework for mapping ecological sanitation practices and technologies. The transect allows for ideas to be laid out across the continuum of rural-urban land use, development intensity, and population density which are important factors in ecological sanitation planning.

*What legal/regulatory, environmental, and public health barriers stand in the way of widespread implementation of ecological sanitation?*

- **Barriers at Local vs. State vs. Federal level?**
- **What ecological sanitation methods are possible within existing legal/regulatory framework?**
  - [How] Does this contrast with ecological sanitation methods optimized for local population, land use/availability, and climatic conditions?

*Centralized versus Decentralized approach to sanitation?*
CHAPTER 5

METHODOLOGY

To create the Ecological Sanitation Transect, a mixed methods approach is utilized. First, each T-Zone is defined by examining common densities, settlement patterns, and building types. Next, case studies are presented to show the reader how ecological sanitation can be undertaken across the development spectrum as well some existing challenges and barriers. Finally, visualizations of the Ecological Sanitation Transect are iterated. These illustrations are visual shorthand for the written explanation and serve to familiarize the audience with contextually appropriate ecological sanitation solutions.

5.1 Case Studies

Case study research offers a way to gain great insights into a topic without getting tied up in time-consuming fieldwork. The Ecological Sanitation Transect defines six distinct yet interrelated T-Zones. Zones are linked to a particular ecological sanitation project occurring within similar density, land use, development pattern, or building type. Each case describes one possible way to implement ecological sanitation in that particular environment. The challenges of securing permits and passing regulatory barriers are examined while successes and lessons learned are drawn out.

5.2 Visualizations

The most important part of creating an Ecological Sanitation Transect is visualizing the concept. As displayed earlier in this work, transects are defined by
graphic representation. A descriptive written explanation most often accompanies this visualization, but the best way to understand the idea is to see it drawn out. As the adage goes, “a picture is worth a thousand words.” When carried out well, graphics and diagrams provide the most direct and intuitive way to access complex ideas. The written word is powerful, but the impression it makes on the reader develops over the course of perusal. Illustrated explanations offer instantaneous inspiration and a means for informing anyone within eyeshot.

To this end a series of graphics is created to show ecological sanitation strategies at both the T-Zone scale and in context along the urban-rural spectrum. The digital renderings are made using Sketchup and Adobe InDesign and Illustrator. By seeing various ecological sanitation implementations in context, the reader better understands both the specifics of the systems and the connections with nearby systems and users. Diagrams visually guide the reader through the ecological sanitation process beginning with collection, followed by treatment of the collected material and finally reuse of sanitized material in agriculture, permaculture, and landscaping settings.

This visual component of the research solidifies ecological sanitation in the canon of transects and is realized as a functional tool within the thesis. The Ecological Sanitation Transect can also be used as an aid in public presentations, a talking point for professional discussion, and a foundation for others to build upon.
CHAPTER 6
THE ECOLOGICAL SANITATION TRANSECT

T-1 The Natural Zone [Figure 14] is based on Duany and Talen’s (2002) Rural Preserve and SmartCode Version 9.2’s (2012) Natural Zone.

T-2 The Rural Zone [Figure 15] is based on Duany and Talen's Rural Reserve, Duany, Plater-Zyberk & Company’s (2014) Rural Communities, and SmartCode Version 9.2’s Rural Zone.

T-3 The Peri-Urban Zone [Figure 16] is based on Duany and Talen’s Sub-Urban, Duany, Plater-Zyberk & Company’s Edge Cities, and SmartCode Version 9.2’s Sub-Urban Zone.

T-4 The Suburban Zone [Figure 17] is based on Duany and Talen’s General Urban, Duany, Plater-Zyberk & Company’s Streetcar Suburbs/Postwar Suburbs, and SmartCode Version 9.2’s General Urban Zone.

T-5 The Urban Zone [Figure 18] is based on Duany and Talen’s Urban Center, Duany, Plater-Zyberk & Company’s Inner City Neighborhoods, and SmartCode Version 9.2’s Urban Center Zone.

T-6 The Urban Core Zone [Figure 19] is based on Duany and Talen’s Urban Core, Duany, Plater-Zyberk & Company’s Central Business District, and SmartCode Version 9.2’s Urban Core Zone.


Figure 20 and

Figure 21 may be used to calculate typical flow rates for residential and commercial buildings at density.
Figure 13: The Ecological Sanitation Transect
The Natural Zone

This area of preserved open space includes surface waterbodies and riparian corridors, protected wetlands and coastal areas. Purchased open space, conservation easements, and utility and transportation corridors may also be found here. This zone also includes areas unsuitable for development due to topography, hydrology, or soil conditions.

Common Density
0 unit/ acres

Common Building Types
Ranger stations, lodges and cabins, utility structures

Collection
Self Contained Composting Toilets
Toilets With Composting Chamber
Pit Latrine

Treatment
Composting Chamber
Constructed Wetlands

Reuse
Soil Amendment
Groundwater Recharge

Figure 14: T-1 The Natural Zone
The Rural Zone

This area may include natural reserves and open space that is not legally protected from development. This zone is characterized by flood plains, aquifer recharge areas, woodland, grassland, and scrubland. Steep slopes. The majority of agriculture occurs here.

Common Density
About 1 unit/20 acres (very low density)

Common Building Types
Farmhouses and agricultural buildings, cabins, resource extraction structures

Collection
Self Contained Composting Toilets
Toilets With Composting Chamber
Urine Storage Tank
Pit Latrine

Treatment
Constructed Wetlands
Windrow Composting

Reuse
Field Fertilizer

Figure 15: T-2 The Rural Zone
The Peri-Urban Zone

This area includes land with medium slope but is defined by single-family detached houses and is almost exclusively residential. Office and retail are allowed by variance only. Setbacks are large. Industrial areas fall within this zone.

Common Density
Between 2-6 units/acre (low density)

Common Building Types
Single-family detached houses, industry buildings

Collection
Self Contained Composting Toilets
Toilets With Composting Chamber
Urine Storage Tank

Treatment
Composting Chamber
Wastewater Gardens
Windrow Composting

Reuse
Garden Fertilizer
Landscaping Fertilizer and Irrigation

Figure 16: T-3 The Peri-Urban Zone
The Suburban Zone

This dry, rolling land is primarily residential with limited office buildings and lodging. Retail is restricted to corner stores in residential sections or shopping centers/strip malls. Uses are Euclidian in nature. Public open spaces take the form of greens and squares. Sidewalks and curbed roads are the norm with small, medium, and large setbacks.

Common Density
Between 4 and 12 units per acre

Common Building Types
Single-family detached houses, rowhouses, shopping centers

Collection
Self Contained Composting Toilets
Toilets With Composting Chamber
Urine Storage Tank

Treatment
Composting Chamber
Wastewater Gardens

Reuse
Garden Fertilizer
Landscaping Fertilizer and Irrigation
Biogas Reactor

Figure 17: T-4 The Suburban Zone
The Urban Zone

This area is mixed use with residential, commercial retail and office space at higher density. Streets are networked, wide sidewalks and street trees are common. Setbacks are small, with buildings oriented to the street. Public open spaces are squares and plazas. Buildings are a maximum of 5 stories.

Common Density
Between 6-24 units/acre (medium-high)

Common Building Types
Rowhouses, apartment buildings, mixed commercial/residential and retail/offices

Collection
Self Contained Composting Toilets
Toilets With Composting Chamber
Urine Storage Tank
Transfer Station Holding Tank

Treatment
Composting Chamber
Wastewater Gardens

Reuse
Landscaping Fertilizer and Irrigation
Biogas Reactor

Figure 18: T-5 The Urban Zone
Urban Core Zone

The densest part of a city, mixed use with residential, business, cultural, entertainment. Streets are often in a rectilinear grid with wide sidewalks and consistent street trees. Mid to high rise buildings and buildings of regional importance. Public open space consists of squares, plazas, and pocket parks/parklets. There are typically no setbacks.

Common Density
Between 12-96 units/acre (high-very high)

Common Building Types
Apartment buildings, office buildings, mixed commercial/residential, department stores

Collection
Self Contained Composting Toilets
Transfer Station Holding Tank
Urine Storage Tank

Treatment
Membrane Bioreactor

Reuse
Landscaping Fertilizer and Irrigation
Biogas Reactor

Figure 19: T-6 The Urban Core Zone
<table>
<thead>
<tr>
<th>Household Size, Number of Persons</th>
<th>Flow Rate, Gal/Capita-D</th>
<th>Household Total-D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Typical</td>
</tr>
<tr>
<td>1</td>
<td>75-130</td>
<td>97</td>
</tr>
<tr>
<td>2</td>
<td>63-81</td>
<td>76</td>
</tr>
<tr>
<td>3</td>
<td>54-70</td>
<td>66</td>
</tr>
<tr>
<td>4</td>
<td>41-71</td>
<td>53</td>
</tr>
<tr>
<td>5</td>
<td>40-68</td>
<td>51</td>
</tr>
<tr>
<td>6</td>
<td>39-67</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>37-64</td>
<td>48</td>
</tr>
<tr>
<td>8</td>
<td>36-62</td>
<td>46</td>
</tr>
</tbody>
</table>

Figure 20: Typical Wastewater Flow Rates, Urban Residential Sources in the US.
Steiner and Butler. 2007

<table>
<thead>
<tr>
<th>Source</th>
<th>Flow Rate, Gal/Unit-D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
</tr>
<tr>
<td>Apartment</td>
<td>Bedroom</td>
</tr>
<tr>
<td>Automobile Service Station</td>
<td>Vehicle served</td>
</tr>
<tr>
<td></td>
<td>Employee</td>
</tr>
<tr>
<td>Bar/Lounge</td>
<td>Seat</td>
</tr>
<tr>
<td></td>
<td>Employee</td>
</tr>
<tr>
<td>Conference Center</td>
<td>Person</td>
</tr>
<tr>
<td>Department Store</td>
<td>Toilet Room</td>
</tr>
<tr>
<td></td>
<td>Employee</td>
</tr>
<tr>
<td>Hotel</td>
<td>Employee</td>
</tr>
<tr>
<td></td>
<td>Guest</td>
</tr>
<tr>
<td>Industrial Building (sanitary waste only)</td>
<td>Employee</td>
</tr>
<tr>
<td>Mobile Home Park</td>
<td>Unit</td>
</tr>
<tr>
<td>Motel (with kitchen)</td>
<td>Guest</td>
</tr>
<tr>
<td>Motel (w/o kitchen)</td>
<td>Guest</td>
</tr>
<tr>
<td>Office</td>
<td>Employee</td>
</tr>
<tr>
<td>Public Lavatory</td>
<td>User</td>
</tr>
<tr>
<td>Restaurant, Conventional</td>
<td>Customer</td>
</tr>
<tr>
<td>Restaurant, with Bar/Lounge</td>
<td>Customer</td>
</tr>
<tr>
<td>Shopping Center</td>
<td>Employee</td>
</tr>
<tr>
<td></td>
<td>Parking Spot</td>
</tr>
<tr>
<td>Theater</td>
<td>Seat</td>
</tr>
</tbody>
</table>

Figure 21: Typical Wastewater Flow Rates, Commercial Sources in the US.
Steiner and Butler. 2007
CHAPTER 7

CASE STUDIES

7.1 T1- Natural Zone: Patos Island, Eastsound WA

The natural zone is preserved open space and undeveloped land. Considerations for this zone include limiting human impact and disturbance on the landscape.

Patos Island is a 207-acre marine park located in Washington’s Spokane District. The island is owned by the US Federal Government and cooperatively managed by the US Bureau of Land Management (BLM) in cooperation with the Washington State Parks and Recreation Commission (WSP). Development on the island is limited to seven campsites, two toilet facilities, and a 1.5-mile trail loop along with a lighthouse built in 1893. Recreation activities permitted on Patos include hiking, camping, boating, and fishing (which requires a license from Washington Department of Fish and Wildlife). Motorized vehicles are prohibited and the island lacks potable water or garbage service; it is a pack-in, pack-out park (Washington State Parks Foundation 2015).

In 2012 the BLM proposed replacing Patos Island’s two existing pit toilets with composting toilets and converting its vault toilet into a maintenance storage building. The BLM cited poor functionality, inability to continue maintenance, surpassing of intended lifespan, and physical deterioration of the facilities as the reasons for the conversion. The intended purpose of the new composting toilets was to provide the public with facilities in good condition that required less
maintenance and could handle increasing visitor usage while minimizing adverse impacts to the island’s natural resources (US BLM 2012, 1).

In terms of ecological sanitation, the Patos Island composting toilet conversion project uses one single and one double unit to collect human urine and feces. The toilets treat the excreta by composting solids and draining excess liquids into a nearby ditch. WSP staff then moves the treated material to adjacent staging areas to cure for two to three years (US BLM 2012, 5). The finished compost is distributed into the natural environment in accordance with Washington State Department of Health’s 1989 Guidelines for Composting Toilets, which state:

The Compost shall not be used directly on root crops or on low-growing vegetables, fruits or berries, which are used for human consumption; however, this general restriction does not apply if stabilized compost is applied 12 months prior to planting… Where it can be shown that sludge will not come in direct contact with the food products, such as in orchards or where stabilized sludges are further treated for sterilization or pathogen reduction, less restrictive periods may be applicable.

The guidelines say that disposal of composted and liquid materials must be done in a manner approved by local health departments and at a minimum comply with Washington State Department of Health’s 1954 Guideline for Sludge Disposal.

In 2006 Patos Island saw about 6000 visitors per year, with the highest period of use falling between May and September. In order to get the project underway, many permitting and regulatory steps had to be taken. The project conforms to the following, among others:
• The National Environmental Policy Act of 1969
• The Federal Land Policy and Management Act of 1976
• The Endangered Species Act (ESA) of 1973
• Migratory Bird Treaty Act of 1918
• Bald and Golden Eagle Protection Act of 1972
• National Historic Preservation Act of 1966
• Native American Graves Protection and Repatriation Act of 1990
• Paleontological Preservation Act of 2009

Due to this site’s location in the natural zone (a remote island in the Pacific Northwest), special care had to be taken in assessing the potential impacts to sensitive, threatened, and endangered species as well as Native American values and cultural resources. Collection, treatment, and reuse of excreta all occur onsite due in part to the limitations of such an isolated locale. This regime also has the effect of limiting disturbances to the environment by forgoing extensive infrastructure and transportation of excreta and compost (US BLM 2012, 2).

7.2 T2- Rural Zone: Rich Earth Institute, Brattleboro VT

The rural zone includes natural reserves and open space and is characterized by features such as flood plains, woodland, and grassland. The majority of agriculture occurs in this zone. Considerations include limiting sprawl development patterns and preserving agricultural land and natural features.
The Rich Earth Institute (REI) is a non-profit research center dedicated to advancing and promoting the use of human waste as a resource (Rich Earth Institute 2015). As a research center, REI carries out scientific studies concerned with using urine as a field fertilizer. Field-tests have occurred at Fair Winds Farm in Brattleboro. Fair Winds Farm is a 42-acre site featuring livestock, vegetables crops, and hay fields. Wild Carrot Farm runs a CSA (community supported agriculture) program from the property (Fair Winds Farm 2015). The farm has two single-family houses and four agricultural buildings (Town of Brattleboro Vermont 2015).

The Rich Earth Institute was founded in 2011 by Kim Nace and Abe Noe-Hays and held its first field tests in 2012. The aim of the Institute’s research is to get urine nutrients out of wastewater to combat pollution. It seeks to shed light on ecological sanitation through demonstration and education projects. Since 2014 REI has been part of a research project with the University at Buffalo, University of Michigan Ann Arbor, and the Hampton Roads Sanitation District to study the presence of pharmaceuticals in recycled urine beginning at soil application, onto crop tissue sampling, and finally to runoff and groundwater (Rich Earth Institute 2015).

Using USDA Sustainable Agriculture Research and Education (SARE) grants, REI has conducted studies in 2013, 2014, and 2015 exploring the use of urine and urine nutrients as fertilizer for agriculture. The 2014 report Sustainable Fertilizer From Reclaimed Urine: A Farm-Scale Demonstration For Hay
Production details REI’s research over the previous year. 3000 gallons of urine were collected from 170 volunteer participants in the Brattleboro, VT area. Urine was collected using urine-only collecting devices as well as urine-diverting toilets (USDA SARE 2014, 1). The collected urine was treated using one of two different methods. Method A involved storing the urine at or above 20ºC for at least 30 days in an unheated greenhouse. Method B used a solar pasteurizer to heat the urine to 70ºC for 30 minutes. After treatment the urine was applied to two hayfields at different rates of dilution. Chemical fertilized and unfertilized fields were also tested. The results showed that the urine and chemical fertilized fields yielded comparable amounts of growth, with the unfertilized field yielding considerably less (USDA SARE 2014, 4-9).

The Rich Earth Institute has met repeatedly with Vermont’s Agency of Natural Resources in order to discuss permits and regulations (Rich Earth Institute 2015).

7.3 T3- Peri-Urban Zone: Cobb Hill Cohousing, Hartland VT

The peri-urban zone is defined by single-family detached houses and is almost exclusively residential. Considerations for this zone include clustering housing to preserve open space.

Cobb Hill Cohousing is an intentional community located in Hartland Vermont. The property features three apartments, six duplexes, and eight single-family houses built close to a common house where residents gather for meals and events. While the residences are clustered at a density of 5 units per acre,
characteristic of the peri-urban zone, the entire property is 280 acres and includes a working farm with agricultural buildings. Cheese, meat, maple syrup, vegetables, and honey are produced annually (Cobb Hill Cohousing 2015).

Donella Meadows, Dartmouth College professor and one of the authors of *The Limits to Growth*, conceived Cobb Hill Cohousing in 1995. Her vision was for a community of people sharing a way of life described as “materially sufficient, socially and ecologically responsible, humanly rewarding, satisfying to the soul…. [and pursuing] the central values of sustainability, sufficiency, community, equity, service, [and] efficiency” (Cobb Hill Cohousing 2015). The land was purchased in 1997, and construction took place from 2001-03.

Cobb Hill’s houses and apartments use individual composting toilet systems with chambers to collect and treat feces and urine. A community-wide septic system handles graywater from all residences. One of the biggest challenges faced in building Cobb Hill Cohousing was sizing the septic system. At the time of design, Vermont did not allow for a reduction in leachfield size to accommodate composting toilets. The community was able to work with the Vermont Department of Environmental Conservation to get a 40% leachfield size reduction for the system. Accounting for this reduction the system was ultimately designed with a 4900 gpd capacity, however actual flow is closer to 1200 gpd. This over design is suspected to be the cause of ongoing clogging issues with the system. Cobb Hill disposes of the compost from its toilets at a burial site on
the property (Franey 2015, 7-8). According to Cobb Hill’s website the composting toilets save 625,000 gallons of water per year.

7.4 T4- Suburban Zone: Sand Creek, Aurora CO

The suburban zone is primarily residential with commercial uses taking the form of corner stores, strip malls/shopping centers, and some office buildings. Considerations for the suburban zone would be managing new growth and accommodating a slightly diverse housing stock. Bikeability and walkability may become feasible at this density so designing for all road users is advised.

Aurora Colorado is a suburban community located 10 miles east of Denver. As of 2014 there were an estimated 347,953 residents. In 2015 the city had 134,655 housing units within its 154.31 square miles limits (City of Aurora 2015). The city’s Sand Creek Water Reuse Facility has been in operation since 1964, with upgrades in 1985 and 2001. The purpose of the system is to provide recycled graywater for irrigation and to reduce demand on the city’s potable water supply (WERF 2015b, 2).

Wastewater is collected from households in the city by the Sand Creek Interceptor, with a capacity of 30 million gallons per day, and sent to an influent diversion structure. Some of influent continues on to the Metro Wastewater Reclamation District Central Plant in Denver while part of it is sent on to Sand Creek’s influent pumps. The Sand Creek Water Reuse Facility can handle 5.5 mgd. The influent is treated by a primary clarifier followed by a biological nutrient removal filter and then a secondary clarifier. Next, the influent gets sent to an
advanced water treatment building where it is filtered and disinfected by UV light. From here the liquid is reused in one of two ways. Some goes to Sand Creek, a tributary of the South Platte River, while the other portion is dosed with chlorine and distributed by pipe to 12 reuse sites within Aurora including parks, greenways, and golf courses. Trucks also transport water to irrigate city parks (WERF 2015b, 1-2).

The Colorado Department of Public Health and Environment (CDPHE) administers permits and oversees monitoring of the plant. National Pollution Discharge Elimination System (NPDES) and Colorado Regulation 84 permits are required to operate. Colorado Regulation 84 governs reuse of water and sets treatment standards:

The regulation…assures these additional uses are consistent with the Commission’s goals of protecting the public health and the environment, by requiring reclaimed domestic wastewater to meet minimum standards, and requiring treaters and users of such water to employ appropriate best management practices and oversee its use (CDPHE 2013, 17).

There are three categories of increasing stringency: Category 1 is the least treated and is not allowed for laundry or vehicle washing, unrestricted access and residential landscape irrigation, or residential and nonresidential fire protection; Category 2 is prohibited from residential landscape irrigation and residential fire protection; and Category 3 enjoys all uses (CDPHE 2013, 6-7).

One of the challenges for Aurora’s water reuse system is the significant fluctuation in reuse water demand depending upon the season. During summer, all water treated by the Sand Creek Facility is used while none is used during
winter. A solution has been to discharge all of the treated water to Sand Creek in the winter for return flow State tax credits (WERF 2015b, 3).

Figure 1: Sand Creek Water Reuse Facility Process Diagram

Figure 22: Sand Creek Water Reuse Facility System, Aurora CO. WERF 2015b

7.5 T5- Urban Zone: Bullitt Center, Seattle WA

The urban zone exhibits a mix of use with residential, commercial retail, and office space at a higher density. Streets are networked and buildings are oriented to the street. Considerations for this zone include limited land area for siting systems and handling collection, treatment, and reuse needs for a mix of uses and users.

The Bullitt Center was built as a new home for the Bullitt Foundation that reflects its mission to protect the Pacific Northwest’s natural environment and promote healthy and sustainable ecosystems (Bullitt Foundation 2014). Located near downtown Seattle, the six-story office building stands at the corner of a
major east-west intersection. Nearby residential uses include detached single-family houses, condominiums, and apartment buildings, including micro housing units. The site is nearby several five- and six-story residential/retail mixed-use buildings with a small park across the street. Significantly, the Bullitt Center is certified to conform to the stringent stipulations of the Living Building Challenge (ULI 2015, 3). The Living Building Challenge closely measures sustainability in the built environment (along the lines of LEED certification) and is performance based rather than prediction based, as such projects are monitored for a year after construction finishes before certification is granted. 21 projects have achieved certification as of 2015. Seven “petals” must be addressed in order to be certified: site, water, energy, health, materials, equity, and beauty. Petal requirements include net zero water and energy, biophilic design, and on-site water treatment, among others (ILFI 2012, 12).

The site for the Bullitt Center was purchased in 2008 and construction was completed in 2013. The building currently has 166 occupants. According to the Building Features section of the Bullitt Center website the building has separate conduits for rainwater, graywater, and blackwater. The roof captures rainwater that is treated to potability first with a vortex filter and then a series of ceramic filters followed by UV disinfection, activated charcoal, and finally low dosed with chlorine before ending up in 500-gallon cistern. Graywater collected from sinks, dishwashers, and showers is held in a 500-gallon tank in the basement. Periodically it is pumped up to a constructed wetland terrace on the third floor
and recirculated several times before being sent to bioswales adjacent to the building to infiltrate into the groundwater. Feces and urine is collected in toilets equipped with foam flush and is conveyed to 10 composting chambers in the basement of the building. The final compost product is removed by the King County Wastewater Division, comingled with municipal biosolids, and further composted with sawdust for a year to produce a soil conditioner called GroCo that is sold in area gardening stores (Bullitt Foundation 2013). GroCo is safe to use in vegetable gardens and landscaping (King County WTD 2015).

To provide regulatory guidance for future LBC projects, the City of Seattle created the Living Building Pilot Program. The Living Building and Deep Green Technical Advisory Group grants variances on behalf of the program and allowed the Bullitt Center to build higher and have solar panels hanging over the sidewalk. Because the building was a first of its kind, careful thought went into selecting team partners to undertake the project. All parties worked together from the start to solve all problems before breaking ground. Although a requirement of the LBC, gaining approval for capturing and treating rainwater for potable use has been a slow process. The Center had to meet with the US EPA, Washington State Departments of Ecology and Health, and Seattle Public Utilities. As of early 2015 the Center is still waiting for approval (ULI 2015, 6).

The Bullitt Center avoids using/discharging 313,742 gallons of water per year. The value of compost produced/ water use avoided is per $7,400 per year
and the annual avoided impact on Seattle’s stormwater system is $9,665 (Ecotrust 2014, 82-84).

7.6 T6- Urban Core Zone: Battery Park City, New York, NY

The urban core zone is the densest part of the transect. It contains a thorough mix of uses with residential, business, entertainment, and civic. Buildings are generally five stories or more. Public open space consists of squares, plazas, and pocket parks/parklets. There are typically no setbacks and sidewalks are wide, often with benches and street trees. Considerations for this zone are the very high population density and space constraints. Creating new infrastructure may pose a challenge.
Battery Park City is a mixed-use development on reclaimed land at the southern end of Manhattan. Administered by the Battery Park City Authority (BPCA), the 92-acre site is home to about 10,000 residents with a transient daytime workforce of 35,000. BPC contains a school, library, public gathering spaces, commercial businesses, apartments, and condominiums. BPCA’s goal for the area has been to maximize real estate value by creating a mixed-use community with fewer negative environmental impacts (WERF 2015a, 2).

At the turn of the new millennium BPCA released two sets of Green Guidelines to shape the development of the area. The Residential Guidelines, first released in 2000, seek to establish building and design standards above those currently required in New York City in an effort to create model buildings that benefit their residents and the environment (BPCA 2005, 7). Energy efficiency, indoor environmental quality, materials and resources, operations and maintenance, and water conservation are all included with requirements, strategies for compliance, and cost implications for each. Buildings must attain a LEED Gold certification. The following is required under innovative water technologies:

“1. Treat all wastewater and reuse to maximum extent possible with an on-site Reclaimed Water Treatment System.
2. Use ecology-based treatment processes (i.e., ultrafiltration), as opposed to a chemical treatment system, for reclaimed water treatment.
3. Use reclaimed water for toilet flushing, cooling tower make-up, irrigation, laundry (to the extent allowed), building and sidewalk maintenance management uses (in all cases, if applicable and properly treated). Provide clearly labeled “Reclaimed Water”
taps wherever treated water is made available to tenants and/or staff. Address the issue of excessive chloride build-up in cooling tower system.

4. Use best efforts to minimize use of chemicals in the maintenance of cooling towers” (BPCA 2005, 59)

The Commercial/Institutional Green Guidelines were released in 2002 with the intent to bring the leadership qualities of the residential guide to commercial and institutional projects. New commercial and institutional buildings are meant to be ecologically responsible and to help educate and influence the real estate market and construction industry about environmental design (BPCA 2002, 3). The Commercial/Institutional Guidelines don’t require LEED certification but do encourage it. The requirements for water conservation include:

“1. Use reclaimed water to flush toilets, for cooling tower make-up, and for irrigation (if applicable and properly treated).
2. Provide separate supply infrastructure for the reclaimed water systems.
3. Locate reclaimed water systems and components on site. Use ecology based natural filtering technology as opposed to chemical treatment. Provide adequate space within the building for storage, treatment and necessary infrastructure.” (BPCA 2002, 14)

Each building (with the exception of two shared systems) has its own wastewater treatment and reuse system as well as stormwater collection. The capacity of individual systems ranges from 15,000 to 40,000 gpd. The total flow rate for all six systems is 175,000 gpd (WERF 2015a, 3). Green roofs and membrane roofs collect stormwater that is then stored in tanks; disinfection and filtration are used in some buildings. Wastewater is treated with Membrane Bioreactor technology. UV and ozone disinfection follow. The treated water is stored in the individual buildings. This reclaimed water is used for cooling,
laundry, toilet flushing, and irrigation. The Solaire was the first residential high-rise constructed in Battery Park City in 2003. The 27-story, 293-unit, 1000-resident building recycles 25,000 gallons of water per day. Collected rainwater is used to irrigate rooftop gardens (American Water 2015).

The systems only treat the amount of wastewater needed to satisfy the non-potable water requirements; the rest is conveyed into the NYC sanitary sewer. All buildings are connected to the NYC potable water and sanitary sewer systems and can be operated directly from these public utilities, bypassing their own systems if the need ever arises (WERF 2015a, 3).

As a result of the construction of Battery Park City, and the initial higher cost of the wastewater reclamation systems, New York City Department of Environmental Protection created the Comprehensive Water Reuse Incentive Program that allows for a 25% reduction in sewer and water rates charged by the city to properties utilizing a water reuse system (WERF 2015a, 7).

Living Machines were originally considered but were taken off of the table due to space constraints. The fact that buildings have individual systems gave the developers flexibility initially, however a neighborhood-wide system serving multiple buildings would benefit from economy of scale and could more easily expand or reconfigure. This has not been implemented but is technically possible. Overall, the fact that New York State does not have water reuse standards was the most significant challenge for this project. Permits for the Battery Park City development are administered by the New York City Building
Department. Board of Health approval, building and plumbing permits, and a State Pollution Discharge Elimination System (for reuse as irrigation in a park) were all required for the project (WERF 2015a, 6-7).

Figure 24: Stormwater and Wastewater Systems for Solaire. WERF. 2015a

Figure 25: Wastewater Treatment System in BPC Buildings. BPCA. 2013
<table>
<thead>
<tr>
<th>Zone</th>
<th>Case Study Location</th>
<th>Collection Method</th>
<th>Treatment Methods</th>
<th>Reuse Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1 Natural Zone</td>
<td>Patos Island, Eastsound, WA</td>
<td>Toilet System with Composting Chamber</td>
<td>Solar Pasteurization</td>
<td>Soil Amendment</td>
</tr>
<tr>
<td>T-2 Rural Zone</td>
<td>Rich Earth Institute, Brattleboro, VT</td>
<td>Urine Storage Tank</td>
<td>Long Term Storage for Graywater</td>
<td>Field Fertilizer</td>
</tr>
<tr>
<td>T-3 Peri-Urban Zone</td>
<td>Cobb Hill Cohousing, Hartland, VT</td>
<td>Toilet Systems with Composting Chambers</td>
<td>Septic System for Graywater</td>
<td>Groundwater Recharge</td>
</tr>
<tr>
<td>T-4 Suburban Zone</td>
<td>Sand Creek, Aurora, CO</td>
<td>Flush Toilets Connected to Influent Pump</td>
<td>Activated Sludge/Biological Nutrient Removal</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>T-5 Urban Zone</td>
<td>Bullitt Center, Seattle, WA</td>
<td>Bioswale and Green Roof</td>
<td>Rooftop Constructed Wetland</td>
<td>Landscape and Garden Fertilizer</td>
</tr>
<tr>
<td>T-6 Urban Core Zone</td>
<td>Battery Park City, NYC</td>
<td>Green Roof and Membrane Roof</td>
<td>Membrane Bioreactor</td>
<td>Graywater and Nonpotable Use</td>
</tr>
</tbody>
</table>

Figure 26: Case Studies Along Ecological Sanitation Transect
7.7 Discussion

With systems ranging from two composting toilets to a 1000-resident, 27-story building these case studies offer valuable lessons to be learned about implementing ecological sanitation across the urban to rural transect. In her paper *Composting Toilets: Alleviating Regulatory Barriers to an Integrated Green Solution*, Tara Franey (2010) identifies three regulatory barriers that composting toilets must overcome: approval of innovative/alternative systems, leachfield reductions, and disposal requirements. These hurdles apply to all ecological sanitation systems and the case studies examined afford solutions for overcoming regulatory as well as economic problems [Figure 27].

<table>
<thead>
<tr>
<th>Regulatory</th>
<th>Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approval</td>
<td><strong>How can ecological sanitation projects be paid for? Private financing or public utility?</strong></td>
</tr>
<tr>
<td>Getting ecological sanitation technologies and systems permitted may pose a challenge.</td>
<td><strong>How might existing requirements for sewer or septic be modified for systems with reduced wastewater?</strong></td>
</tr>
<tr>
<td>Approval</td>
<td><strong>What are the applications a regulatory body is comfortable with in regards to reuse of ecologically sanitized excreta and recycled graywater?</strong></td>
</tr>
<tr>
<td>Disposal/Reuse</td>
<td><strong>Public pays in full (Patos Island)</strong></td>
</tr>
<tr>
<td>Allow for leachfield size reductions (Cobb Hill)</td>
<td><strong>Field fertilizer (REI)</strong></td>
</tr>
<tr>
<td>Field fertilizer (REI)</td>
<td><strong>Public pays in full (Patos Island)</strong></td>
</tr>
<tr>
<td>Landscape and garden compost (Bullitt Center)</td>
<td><strong>Public pays and charges users (Sand Creek)</strong></td>
</tr>
<tr>
<td>Create new standards and regulations (Bullitt Center)</td>
<td><strong>Developer pays with credits/incentives from public (Bullitt Center and BPC)</strong></td>
</tr>
<tr>
<td>Institute a Comprehensive Water Reuse Program (BPC)</td>
<td><strong>Developer pays with [research] grants (REI)</strong></td>
</tr>
<tr>
<td>Landscape irrigation, toilet flushing, laundry, cooling (BPC)</td>
<td><strong>Developer pays with credits/incentives from public (Bullitt Center and BPC)</strong></td>
</tr>
<tr>
<td>Grades of graywater (Sand Creek)</td>
<td><strong>Developer pays with [research] grants (REI)</strong></td>
</tr>
<tr>
<td>Adopt progressive industry standards (like LEED and LBC)</td>
<td><strong>Onsite disposal/burial (Patos and Cobb Hill)</strong></td>
</tr>
<tr>
<td>Fully integrate systems with public utilities (BPC)</td>
<td><strong>Developer pays in full (Cobb Hill)</strong></td>
</tr>
</tbody>
</table>

Figure 27: Overcoming Barriers to Ecological Sanitation
CHAPTER 8

CONCLUSION

The Ecological Sanitation Transect is a tool for planners, public officials, and interested citizens. By understanding the history of sanitation it is clear that paradigm shifts have intended benefits as well as unintended consequences. By rethinking sanitation holistically it becomes clear that growing food, eating food, expelling feces and urine, treating excreta, and fertilizing crops are cyclically linked. Conventional gray infrastructure and water-based conveyance sanitation have disrupted this cycle and turned it into a linear operation where acquiring fertilizer and disposing of human wastewater are unrelated problems without easy solutions rather than regenerative steps in a reoccurring process.

8.1 Implementation

The implementation of ecological sanitation is not a one-size-fits-all procedure. Instead the myriad technologies and methods for collection, treating, and reusing human excrement nutrients, graywater, and stormwater must be carefully selected and intertwined based on context. The transect acts as a framework to organize population density, building type, and land use into the six T-Zone categories from rural to urban context. The Ecological Sanitation Transect is not intended to be a set in stone; rather it is an overview of the possibilities of ecological sanitation.
8.1.1 Inter-Zone Flows

The vision of the Ecological Sanitation Transect is a regional one. While each zone has contextually unique opportunities and limitations for collection, treatment, and reuse, the zones do not exist in a vacuum. T-5 and T-6 are the most densely populated areas and have the greatest potential for collection. These zones however are limited in the strategies they can employ for treatment and especially reuse due to limited available land. In contrast, T-2 is where most of agricultural production occurs along the Ecological Sanitation Transect. As such, it has the greatest opportunity for reuse of treated excreta [Figure 28]. Because T-3 and T-4 have some collection and reuse potential but also have available land and existing industrial and transportation infrastructure, they have the highest potential for treatment.

Figure 28: Potential Collection and Reuse Along Transect
This understanding presents a regional planning strategy for ecological sanitation: balance collection and reuse by bringing excreta from urban areas to be treated in suburban and peri-urban areas so it can be reused in rural areas. Production and consumption, the other half of the nutrient cycle, have long been understood in the development of food systems: crops are grown in rural areas but must be brought to the hungry masses in urban areas.

8.1.2 Growth Management

Feiden and Winkler (2006, 24-26) note that communities often use sewerage regulations to guide growth. This approach can be problematic however as requirements for siting septic systems and other conventional, decentralized sanitation systems may have the effect of encouraging sprawl or increasing development pressure on farmland. While decentralized and small-scale sanitation systems should be part of a comprehensive community vision for resource protection and treatment of excreta, ecological sanitation offers many options for infill. Diversity is one of the strengths of ecological sanitation; myriad technologies and systems exist for collecting, treating, and reusing human excreta and graywater. Treatment systems such as waste stabilization ponds and windrow composting require proportionally large areas of land, but self contained and chambered composting toilets are easily accommodated in basements. Bioreactors and graywater recycling systems such as those in Battery Park City are essentially self contained; all treatment and most reuse occurs within the building. Redundancy may be another way to plan for growth.
with ecological sanitation. By requiring BPC’s building-scale ecological sanitation systems to be hooked up to the city sewer, the opportunity to connect to a future neighborhood- or district-scale system has not been lost. In *Distributed Water Infrastructure for Sustainable Communities: A Guide for Decision-Makers*, WERF (2010) introduces the Wastewater Management Continuum as a way to think about the integration of decentralized and centralized treatment systems [Figure 29]. As growth occurs over time and density increases, consolidating site-scale systems into multi-building or neighborhood-wide systems may be a good option for a community.

Figure 29: The Wastewater Management Continuum. WERF. 2010
8.1.3 Monitoring

Monitoring and maintenance are very important parts of ecological sanitation systems. In order to make sure they are functioning properly and meeting sanitary thresholds, inspection of systems is highly recommended. Title 5 of the Massachusetts State Environmental Code is a good example of sanitation regulation that includes both privately owned conventional and alternative systems (MassDEP 2014, 60-77). If a building is going to be sold, expanded, or converted to a different use its sanitation system is subject to inspection. The regulation does not specify whether the buyer or seller will pay for repairs if the system fails, this is negotiated during the transaction. If the system does fail, the responsible party may qualify for local, state, or federal grants and tax credits to help cover the cost of repair or replacement (MassEEA 2015). In this way the ecological sanitation system has a good chance of remaining in place as ownership of the property changes over time.

8.1.4 Regulations

Local, State, and Federal regulations differ widely in regards to alternative or innovative sanitation systems (as opposed to conventional systems). The most significant federal regulation is the National Pollution Discharge Elimination System permit, required for discharging into waterbodies. Local and state governments generally set wastewater regulations though few states explicitly mention composting toilets or ecological sanitation systems (Feiden and Winkler 2006, 18). Most do have channels for getting alternative or innovative sanitation
systems approved. Voluntary regulations are available from non-governmental entities; Oregon adopted the International Green Construction Code (IgCC) in 2012 with amendments to become the Oregon Reach Code. The purpose of this code is to link safety and performance to sustainability. The Reach Code has a section dedicated to residential composting toilets and details design, composting, management, installation, and operation (International Code Council 2010, 12-13).

An interesting grassroots organization called Recode is seeking to create model regulations for green building and development. In 2014 Recode created the draft *National Plumbing Code for Composting and Urine Diversion Toilets* and submitted it to the International Association of Plumbing and Mechanical Officials (IAPMO). Their aim for this voluntary regulation is for strict protection of public health while encouraging growth in the US composting toilet industry (Recode 2014).

8.2 Directions for Future Research

The Ecological Sanitation Transect has been laid out in this work as a new tool for waste management and regional planning. However the idea is worth further exploration and reflection. There are several areas not fully researched that deserve more inquiry.

8.2.1 Retrofitting (Converting From Gray To Ecological)

While the Ecological Sanitation Transect is a tool that may be quite useful for planning new development in a community or region, the prospect of
changing over from an existing gray infrastructure system has not been addressed. Perhaps homeowners and businesses should be incentivized to replace their plumbing and fixtures with composting toilets and graywater recycling systems. Or perhaps it makes sense to convert when building new or redeveloping.

8.2.2 Centralized versus Decentralized

One of the concepts the author would most like to explore further comparing centralized to decentralized ecological sanitation systems. The case studies and technologies presented in this work exhibit both strategies. While decentralized, onsite systems do have advantages such as flexibility, resource conservation, and personal interest and responsibility for one’s excreta, centralized systems offer a simplified way to manage collection, treatment, and reuse. The sizing and upgrading of centralized waste systems is more closely understood, while new growth and development may make an increasing number of decentralized systems problematic.

8.2.3 Taboo/acceptance

A social science aspect of ecological sanitation that should be further explored is how to inform and work with a public who may be averse to recycling their own excreta. It is possible that education could play a role. Giving a local and global overview of the history of sanitation and explaining the concept of the nutrient cycle could be a first step. If a public is informed, or better shown, how their current sanitation system functions they may be more open to alternative
systems. Leading tours of ecological sanitation facilities would also educate community members about the possibilities of collection, treatment, and reuse. Allaying fears might be accomplished by explaining common misconceptions of ecological sanitation and the long-term cost savings and environmental benefits should not be understated.
REFERENCES


Adamsson, M. 2000. "Potential use of human urine by greenhouse culturing of microalgae (Scenedesmus acuminatus), zooplankton (Daphnia magna) and tomatoes (Lycopersicon)." Ecological Engineering 16, no. 2: 243-254.


