Center for Water and Environmental Sustainability (CWESt)
Annual Technical Report
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Introduction

Oregonians are beginning to witness the difficulties caused by water limitations. Water quantity and quality issues in the Willamette and Klamath Basins are the Governor's top environmental priorities. This situation is paralleled around the world, and points toward a strong emerging area for growth in research, education, and outreach. OSU is ideally positioned to assume a leadership role in addressing water problems, with about 80 faculty in six colleges who teach and conduct research in areas related to water and watersheds. OSU is renowned for its landscape-scale ecosystems research and has just initiated five new graduate degree programs in Water Resources. These research and education efforts have all occurred without the benefit of programmatic coordination or strategic vision.

The Water and Watersheds Initiative developed by OSU in 2005 is designed to replace the Center for Water and Environmental Sustainability (CWEST) to better leverage OSU's existing excellence in water and watersheds by 1) providing coordination of water and watershed activities at OSU, 2) creating an innovative, place-based educational approach connecting a diverse student body with relevant issues across the state, 3) enabling capture of new, high-value opportunities for research, education, and outreach, 4) engaging OSU faculty and students with external stakeholders throughout the state, and 5) establishing a set of shared water and watershed collaboratories supporting research, teaching and outreach. This initiative will increase the diversity and quality of OSU students involved in water resource activities, and advance OSU's Strategic Plan and Land Grant mission.

Coordination and leadership are key to achieving these goals. The Initiative is funding a new Institute for Water and Watersheds (IWW), led by a nationally prominent Director, Dr. Michael Campana, to pull faculty and resources together to tap the huge potential for new funding. This institute will catalyze and support the growth of academic programs; state of the art laboratories; enhanced outreach to Oregon's communities; and development of real solutions for Oregon's critical water resource issues. The WW Initiative will create a physical and intellectual center for water at OSU that focuses faculty, students, facilities, and activities in a common location through four specific efforts: 1) a university-wide water services lab supported by a full-time technician that provides services to multiple researchers and teachers; 2) home offices for visiting scholars, fellows, and OSU faculty as necessary; 3) video-conferencing capacity for teaching, research, and outreach activities; and 4) co-location with the Institute of Natural Resources to provide links to policy, information, and research activities throughout the state of Oregon.

To create a diverse student population able to address complex water resources issues, the Initiative will fund the development of an innovative, multi-disciplinary learning environment through five specific mechanisms: 1) development of a place-based platform for learning in the Oak Creek watershed for integrating a water resources curriculum across multiple courses; 2) development of two new, interdisciplinary synthesis courses addressing relevant water resource issues in Oregon; 3) sponsorship of Diversity & Excellence scholarships to increase access and diversity in the water resources student population; 4) development of a common information repository integrating water resource courses, research activities and, outreach efforts designed to enhance student learning across multiple courses; and 5) support through a competitive funding process of activities designed to capture new, external resources focused on academic program innovation.

A central aspect of this Initiative is the development of new and innovative ways to engage stakeholders across the region: The Initiative will allow OSU scientists and students to connect with diverse decision-makers at the federal, state and local levels to provide solutions to Oregon's water problems through three activities: 1) incorporation of stakeholder needs and experiences into the Water and Watershed curriculum; 2) sponsorship of a series of collaborative workshops held around the state with federal, state and local stakeholders to identify partnering opportunities for addressing high-profile issues in Oregon; and 3) establishment of a biennial conference, co-sponsored with the Governor's Natural Resources Office to engage the Oregon legislature and state and federal agencies, to identify critical water and watershed issues in the State and develop strategies to address these issues.

The Water and Watersheds Initiative will fundamentally elevate OSU's current capabilities in realizing new opportunities and attracting new funding sources while better serving the needs of students and the state. The outcome will be a thriving academic engine built on current investments and existing excellence aligned with the OSU strategic plan - interdisciplinary collaboration; the land-grant mission; national and international dimensions; diversity; the environmental and economic health of the state, and will lead to a strong, self-sustaining unit that will continue to strategically leverage state investment to solve the water problems of the future.

Research Program

Hydrogeomorphic Analysis of the Luckiamute Watershed, Central Coast Range, Oregon:

Basic Information

Title:	Hydrogeomorphic Analysis of the Luckiamute Watershed, Central Coast Range, Oregon:
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Start Date:	2/15/2004
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Publication

1. The extensive listing of reports and data files for this project can be viewed at http://www.wou.edu/luckiamute

FINAL PROJECT REPORT
U.S. GEOLOGICAL SURVEY SMALL GRANTS PROGRAM

Hydrogeomorphic Analysis of the Luckiamute Watershed, Central Coast Range, Oregon: Integrating Applied Watershed Science with Undergraduate Research and Community Outreach

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<u>Project Focus Categories</u>

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PROJECT DESCRIPTION

Mountainous watersheds are fundamental landscape elements that form an important setting for local ecological interactions, human occupation, and water resource development. They also represent the foundational components for mass sediment transfer from continental regions to ocean basins. As such, the understanding of hydrogeomorphic variables is critical for designing sustainable water resource and habitat conservation plans. From the perspective of undergraduate training in the Earth Sciences, watersheds represent the ideal natural laboratory for student application of quantitative techniques to multivariate systems with interdependent process-response mechanisms.

This project, initiated in spring 2004, involved hydrogeomorphic analysis of the Luckiamute River basin (A_d = 815 km^2) in western Oregon (Figure 1). The Luckiamute is being used as a model watershed to integrate select components of applied research into a sequence of surface-process courses at Western Oregon University (WOU). Faculty and undergraduate Earth Science majors are currently engaged with integrated studies in fluvial geomorphology, environmental geology, hydrology, and GIS analysis. From a training perspective, the watershed-based curriculum: (1) incorporates research into the undergraduate Earth Science program at WOU, (2) engages students in socially-relevant watershed-based science (e.g. Woltemade and Blewett, 2002), (3) improves quantitative skills via coursework, lab exercises and applied research, (4) develops problem-solving and scientific skills within a regional watershed setting, and (5) fosters an interconnected perspective of watershed processes across several linked courses. The research model is placed in the context of community outreach via collaboration with a local watershed council.

The outcomes of this project are summarized in Table 1, they include: (1) a set of contextual, watershed-based, learning modules and field guides for use in an integrated course series, (2) community outreach via faculty-student interaction with the Luckiamute Watershed Council, a community-based organization dedicated to water resource conservation, (3) publishable research on hydrogeomorphic aspects of the Luckiamute Watershed, and (4) dissemination of a watershed-based undergraduate education model (www.wou.edu/luckiamute). The resulting research objectives focused on lithologic control of drainage basin morphology and characterization of local aquifer systems. In addition, the USGS funding and incentives to conduct this work have led to numerous synergistic activities, all of which are described below.

PROJECT RESULTS

Undergraduate Training and Support

Integrating undergraduate research and education in the sciences is recognized as an important model for preparing students to participate in the 21st century workforce (National Science Foundation, 2003). College graduates are increasingly required to understand complex integrated systems by applying multi-disciplinary problem solving skills. As such, there is a general lack of linked science curricula in which students systematically build a set of problem-solving skills that are applied to real-world problems (Heins and Walker, 1998). Watershed systems represent the interaction of physical and biological processes at spatial and temporal scales that are highly relevant to the community at large (Woltemade and Blewett, 2002). The results of this project form the framework for undergraduate training in applied fluvial geomorphology (ES322), environmental geology (ES473), hydrology (ES476), and applied geographic information systems (ES492) at Western Oregon University.

Ten contextual learning modules and three class-related field trip guides were created with the Luckiamute Watershed serving as the outdoor laboratory for inquiry-based, experiential discovery (Table 1, Figure 2). The learning modules include GIS techniques, field hydrology, case studies in groundwater contamination, geomorphic analysis, watershed assessment, and value-added utilization of USGS stream gage data. The Luckiamute field guides involve a range of topics including regional geology, tectonic setting, hydrogeology, environmental quality, and solid waste management. With the Luckiamute serving as the unifying theme, upper division students are exposed to linked modules distributed across four surficial-process courses, thus integrating concepts and reinforcing a watershed systems approach to Earth Science education. Specific details of the curricular products derived as part of this project are available for online review at http://www.wou.edu/luckiamute.

During the course of this project, seven WOU undergraduates were supported as research assistants: Jeff Budnick, B.S. Earth Science (graduated June 2005); Chandra Drury, B.S. Earth Science (graduated December 2005); Jamie Fisher, B.S. Earth Science (expected graduation Spring 2006); Diane Hale, B.S. Physical Geography (graduated August 2004); Jeff Kent, B.S. Earth Science (expected graduation Spring 2006); Katie Noll, B.S. Earth Science (expected graduation Winter 2007); and Rachel Pirot, B.S. Earth Science (expected graduation Fall 2007). The primary research activities conducted by the students included literature review, data compilation, GIS analysis, scientific visualization, and field geomorphology (Figure 2). In addition, the research and learning modules from this project will have lasting impact to present and future Earth Science students enrolled in

ES322 Geomorphology (n = 8-12 students / term), ES473/573 Environmental Geology (n=8-12 students / term), ES476/576 Hydrology (n= 8-12 students/term), and ES 492/592 GIS Applications in Earth Science (n = 8-12 students/term).

Community Outreach

Research, service and educational activities at Western Oregon University are directly connected to the community by way of outreach to the Luckiamute Watershed Council (LWC). WOU provides office space, computing facilities, and support services for LWC. The watershed coordinator is housed in close proximity to faculty, resulting in weekly synergistic interaction. During the course of this grant, two LWC coordinators were trained and indirectly supported as research associates: Eve Montanaro (B.S. Physical Geography, 2002, University of Oregon) and Michael Cairns (retired EPA). Community outreach activities, centered on the Luckiamute Watershed, have resulted in a number ancillary projects involving faculty and students. Value-added community products include stakeholder opinion surveys, scientific advisement on watershed assessment, assistance on restoration projects, seminars/field trips, general board advisory activities, and GIS technical support.

Research Results

Bedrock Controls on Watershed Morphology

Studies in the Oregon Coast Range have yielded numerous contributions to the understanding of mountain river systems. Published research topics include sediment budget analysis, sediment transport models, debris flow dynamics, hillslope hydrology, landslide risk modelling, effects of punctuated sediment supply, landscape evolution, and tectonic controls on bedrock erosion rates. While this rich body of work has significantly improved our geomorphic understanding of mountain river systems, most studies have been limited to landscapes underlain by bedrock of the Eocene Tyee Formation (Taylor, 2005). Few studies have been conducted in portions of the Oregon Coast Range underlain by other lithostratigraphic units. Work in other bedrock domains is needed to assess the applicability of existing models to other Coast Range landscapes. This study involved comparative morphometric analysis of HUC 6th field watersheds, using Tyee-based landscapes as a benchmark for comparison with other bedrock types in the central Oregon Coast Range.

The Luckiamute River watershed drains 815 km^2 along the east flank of the Coast Range in west-central Oregon (Figure 1). The basin is bounded by the Willamette River to the east, the crest of the Coast Range to the west, Green Mountain and Marys River to the south, and the Rickreall Creek

Watershed to the north. Land surface elevations range from 46 m (150 ft) at the confluence with the Willamette River to 1016 m (3333 ft) at Fanno Peak. The Luckiamute has an average gradient of 3 m/km, a total stream length of 90.7 km, and an average basin elevation of 277 m (910 ft). Fanno Ridge separates the watershed into two tributary subbasins, with the Little Luckiamute to the north and the main stem of the Luckiamute proper to the south (Figure 1).

Bedrock map units are grouped into four lithospatial domains, these include the Siletz River Volcanics Domain (south), the Tyee Domain (west-southwest), the Yamhill-Intrusive Domain (north-northwest), and the Spencer-Valley Fill Domain (east) (Figure 3). The Siletz River Domain comprises 19% of the watershed and is mainly seafloor basalt. The Tyee Domain (29% of total area) is underlain by arkosic sandstone lithofacies with local mafic intrusives. The Yamhill-Intrusive Domain occupies 23% of the watershed and is characterized by outcrop of marine siltstone and mafic intrusives. The Spencer-Valley Fill Domain (29%) is underlain by a patchwork of marine sandstones and Quaternary alluvium. Hillslope landforms and colluvial processes dominate the Siletz River, Tyee, and Yamhill domains, whereas fluvial landforms and alluvial processes are characteristic of the Spencer Domain (Figure 4).

Fourth-order subbasins (n = 5-6, avg. Ad = 16 km^2) were selected from each bedrock domain for subsequent terrain analysis of USGS 10-meter DEMs (Figure 5). Subbasin boundaries and channel networks used in this study are thosed derived by the Coastal Landscape Analysis and Modeling (CLAMS) group at Pacific Northwest Forest Research Lab (Miller et al., 2001). Results of comparative morphometric analyses are presented in Figure 6. Averaged quantitative parameters for the Spencer, Siletz, Yamhill, and Tyee domains include, respectively: **(1)** hypsometric integral (0.30, 0.40, 0.48, 0.29), **(2)** basin ruggedness (0.2, 1.2, 1.1, 1.6), **(3)** total drainage density (1.4, 2.3, 2.0, 2.4 km^{-1}), **(4)** Shreve magnitude (14, 49, 31, 55), **(5)** first-order stream density (0.7, 1.2, 1.0, 1.2 km^{-1}), **(6)** channel gradients (0.04, 0.13, 0.18, 0.14), **(7)** stream power index (69, 1909, 2534, 1133), **(8)** hillslope gradients (3.2, 12.7, 11.9, and 14.5 degrees), and **(9)** hillslope profile curvature (0.004, 0.008, 0.007, 0.011 m/deg). The Tyee Domain is more finely dissected by low-order stream channels and associated with more rugged hillslopes compared to the other three domains. Results of the slope analyses are consistent with debris-flow hazard models released by the Oregon Department of Forestry, suggesting that hillslopes in the Tyee Domain are most prone to slope failure (percent of domain area in hazard zone: Tyee = 38.1, Siletz = 30.2, Yamhill = 24.6, and Valley Fill = 0.7). Morphometric analysis of higher-order valley widths at 500 m increments shows that trunk drainage across the Tyee Domain covers a much wider swath of valley floor (avg. W_v = 274 m) compared to a similar-sized drainage area in the Yamhill Domain (avg. W_v = 109 m) (Figure 7). Stream power parameters suggest that while Tyee drainages are more energetic than the Spencer system, they are less potentially less effective at sediment transport than the other upland domains (Figure 6C). These data suggest that bedrock lithology exerts a strong control on hillslope morphology, style of hillslope process, and sediment-transport efficiency in headwater portions of the Luckiamute.

The interplay between hillslope transport mechanisms, delivery rates, and channel hydraulics control the volume of sediment exported or stored within a mountainous watershed. The comparatively steep, debris-flow-prone slopes and wide valley bottoms in the Tyee Domain indicate a potential for hillslope transport rates to be greater than the ability of the channel system to export sediment. Analytical results presented herein provide a preliminary dataset upon which to build a field-based sediment-storage budget for the Luckiamute watershed. The working hypothesis is that the Tyee Domain has a significantly greater volume of valley-bottom sediment in storage compared to the other upland domains (Siletz, Yamhill) (Figure 8). The model implies that spatial variation of bedrock lithology is a primary factor controlling slope gradients, hillslope delivery rates, and the resulting sediment-transport efficiency of the channel system. The rich body of work from other Tyee-based landscapes in the Oregon Coast Range will serve as the platform from which to extend future research in the Luckiamute to other bedrock domains.

Hydrogeologic Characterization

Gannet and Caldwell (1998) and Woodward et al. (1998) delineated the principle hydrostratigraphic units in the Southern Willamette Basin. In ascending order these include: (1) basement confining unit (BCU), (2) Willamette confining unit (WCU), (3) Willamette aquifer (WAq), and (4) Willamette Silt (WS). The lowermost unit is represented by indurated bedrock, while the latter three are comprised of unconsolidated alluvium and valley-fill sediments. Alluvial-fill thickness in the lower Luckiamute and Ash Creek sub-basins ranges up to 30 m (100 ft) with most localities in the 12 to 24 m (40 to 80 ft) range. Luckiamute alluvial-fill thickens to the east towards the center of the Willamette Valley, and thins upstream to a minimum near the communities of Falls City and Pedee (Caldwell, 1993; Gannett and Caldwell, 1998).

The basement confining unit is composed predominantly of Tertiary marine sedimentary rocks and related submarine basalts. This unit is characterized by relatively low permeability lithofacies with intermixed low-yield aquifer horizons and aquitards. In the lower Luckiamute and Ash Creek subbasins, BCU is composed largely of Spencer Formation strata. The Siletz River Volcanics form the basement unit in the southern portion of the watershed, along Soap Creek (Figures 3 and 9).

The Willamette confining unit is composed of unconsolidated fine-grained fluvial facies deposited by low-gradient streams during the Pleistocene. Drilling logs commonly refer to this unit as “blue clay”, “silty clay” or “shale", containing laterally discontinous sandy and gravelly interbeds. WCU is characterized by limited ground water production, however coarse-grained interbeds locally serve as aquifers. Regional yields from wells set in this unit range from 2 to 10 gallons per minute (Table 2). WCU thickness in the study area ranges from a maximum of 18 m (60 ft) at Luckiamute Landing, to less than 6 m (20 ft) upstream of Helmick State Park. The Willamette confining unit is less than 18 m (60 ft) thick in the Ash Creek subbasin.

The Willamette aquifer is composed of coarse-grained facies associated with Pleistocene alluvial fans and deposits of smaller side tributaries. This unit was referred to as the "Linn Gravel" by Allison (1953). It is characterized by thick-bedded sand and gravel facies with thin interbeds of fine-grained sand, silt and clay. WAq is locally cemented and partially indurated. Regionally, the Willamette aquifer is formed by fluvio-glacial outwash from large drainage systems in the Cascades that debouch westward onto the valley floor. Given lower summit elevations, the Coast Range was not glaciated during the Pleistocene. Thus eastward-draining tributaries to the Willamette, including the Luckiamute, tend to be smaller in area compared to those of the western Cascades, and are not associated with high-volume fluvio-glacial aquifer systems. The lower end of the Luckiamute lies approximately 30 km (18 mi) west of the Stayton and Lebanon fans, deposits of the North and South Santiam Rivers, respectively. Given the distal position of the Luckiamute in relation to large fan deposits, WAq gravels in the watershed are generally less than 6 m (20 ft) thick and are likely composed of sediments derived locally from Coast Range sources.

The Willamette Silt is the uppermost valley-fill unit and is comprised of late Pleistocene Missoula Flood deposits (map unit Qff2 of O’Connor and others, 2001). Fine-grained clay, silty clay, and silt occurs up to an elevation of 120 m (400 ft) in Luckiamute Basin and is less than 6 to 9 m (20 to 30 ft) thick (Table 2). This unit serves as a semi-confining aquitard for the Willamette aquifer, however it is partly saturated and is commonly associated with water table conditions throughout much of the Willamette Basin.

In addition to the valley ground-water system, a significant portion of the Luckiamute is served by upland bedrock aquifer horizons set in strata of the Siletz River Volcanics, Tyee Formation, Yamhill Formation, and Oligocene Intrusives. Crystalline volcanic and intrusive rocks have inherently low porosity and permeability, but secondary fracture porosity can be significant (Freeze and Cherry, 1979). In the case of the Siletz River basalts, low-grade alteration and secondary zeolitization has likely resulted in significant reduction of hydraulic conductivity. Similary, the fine-grained nature of the Tyee and Yamhill formations makes them of limited value as aquifer material (Table 2).

Hydrogeologic data were collected from field-located wells as part of the Willamette Regional Aquifer Systems Analysis (RASA) conducted by the U.S. Geological Survey (Woodward and others, 1998; Gannett and Caldwell,1998). Approximately 40% of well heads are located in unconsolidated valley-fill alluvium, with 60% situated in basement-confining or upland bedrock units (Table 2). Given that maximum alluvial fill in the Luckiamute-Ash Creek basins is generally less than 30 m (100 ft), all of the wells in the inventory have bottom depths situated in the basement-confining or upland bedrock aquifers. Average depth relations reveal that the bedrock wells have greater total depths and lower static water level elevations compared to wells situated on valley fill. Although quantitative hydraulic analyses are lacking in the Luckiamute, Gonthier (1983) documented hydraulic conductivities in the range of 0.2 to 0.3 ft/day for the Dallas-Monmouth Area. Accordingly, the average specific capacity for wells ranges from <1 to 7 gallons per minute per foot of drawdown (Woodward and others, 1998).

The Spencer-Valley Fill domain in the Luckiamute forms part of the regional Willamette aquifer system which is generally associated with unconfined potentiometric conditions. Valley-fill aquifers in the Ash Creek subbasin are hydrogeologically separated from the Luckiamute by a hydraulic divide comprised of low-permeability lithofacies in the Spencer Formation (basement confining unit of Gannett and Caldwell, 1998). The lower Luckiamute valley-fill aquifer system is characterized by eastward ground water flow and hydraulic gradients on the order of 5 ft/mi (Woodward and others, 1998). Unconsolidated valley fill is more prevalent in the Ash Creek subbasin with eastward-directed hydraulic gradients of 20 ft/mi (Caldwell, 1993). Regionally, seepage velocity in the Willamette aquifer ranges from 3 to 30 ft / day, comparable to other coarse-grained aquifers. Iverson and Haggerty (2002) conducted research in the Willamette Silt to determine hydraulic and geochemical properties. The results of their work along the Pudding River suggests that WS serves as a confining unit to the underlying Waq. Horizontal hydraulic conductivities are on the order of 0.004 to 5.53 ft/day, with vertical permeabilities of 0.008 ft/day and porosity of 40%.

Natural ground water quality ranges from good to poor in the Luckiamute-Ash Creek subbasins. Caldwell (1993) documented localized high salinity concentrations in the Monmouth-

Independence area. His study utilized trace element analyses to relate bedrock mineralogy to ground water residence times and salinity contamination risk. The results indicate that ground water in the region is associated with chloride-dominant ionic species ($CaCl_2$ and NaCl) and poses a potential water quality hazard. It is interpreted that increased salinity levels are derived from connate brine waters trapped in Tertiary marine sedimentary rocks. This saline water mixes with shallow ground water via upward migration along folds and faults in the basement confining units. Preliminary analyses of water quality data to the south indicate that similar salinity conditions may also be present in Luckiamute aquifers. Detailed quantitative analyses of Luckiamute aquifer systems are needed to delineate the physical and chemical nature of hydrogeologic processes in the basin.

SYNERGISTIC ACTIVITIES

The funding and activities associated with this project provided the catalyst for synergistic collaborations and additional research opportunities in the Luckiamute basin. A sampling these ancillary projects is provided below.

Stream Temperature Survey

(Taylor and WOU Students; WOU Foundation Funding)

Studies elsewhere in Oregon suggest that groundwater flux to streams during the summer and stream temperature are dependent on geology, with fractured or porous formations producing the highest flows per unit drainage area and the coolest streams. A comparison of small watersheds in the mid-Coast Range of Oregon indicated that those underlain by highly-fractured marine basalt have summer base flow volumes that average 3 times greater than those underlain by sandstone (Hicks 1990). Similarly, streams flowing through the central High Cascades in Oregon have unit summer flows that are 14 times greater than those flowing through the Western Cascades (Tague and Grant, 2004). Accordingly, streams draining the High Cascades are an average of 5 degrees cooler than those draining the Western Cascades.

Low flows combined with warm summer climate result in stream temperatures for portions of the Luckiamute watershed that sometime exceed the limits for juvenile steelhead trout survival and growth. The warmer stream segments in the watershed generally occur at greater distances from the headwaters. Data collected by the Oregon Department of Environmental Quality (2001) indicate that it is mainly the portion of the stream network within 15 miles of a drainage divide that is cool enough to sustain steelhead trout during the warmest part of the summer, assuming that fish will continue to occupy water that is 70 degrees or cooler (Figure 10). Streams that do not have adequate shade (shown as circles in Figure 10) are capable of approaching or exceeding 70 degrees even at closer distances to the headwaters. Fish are able to use marginally warm streams by congregating in localized zones of cooler water during the warmest part of the day. Cool water can occur at discrete points where groundwater enters (springs), become stratified at the bottom of deep pools, and occur where subsurface water flowing through gravel deposits is intercepted by the stream channel. These cool water zones are expected to be more common in porous lithologies.

With funds provided by a private donation for Luckiamute watershed research at WOU, a systematic stream temperature survey will begin in summer 2006. The objectives of this project are to compare summer low-flow stream temperatures in the Tyee domain to those of the Siletz. Stream temperatures will be examined in tandem with reach-scale discharge to evaluate the relative contribution of groundwater baseflow in each of the lithospatial domains. The preliminary hypothesis is that the streams in the marine basalts will have higher unit flows, lower overall water temperature, and greater frequency of cool water refugia when compared to streams in the Tyee domain. Differences in water characteristics between the two lithospatial domains may be great enough to influence the distribution and carrying capacity of cool-water communities of fish that use these channel systems. The results will have important implications for guiding salmonid recovery efforts in the Luckiamute basin.

Invasive Plant Study

(Bryan Dutton-WOU Biology and Taylor; funded by Oregon Community Foundation)

Invasive plant species in western Oregon are a pervasive problem that disrupt native habitats and create annual economic losses of millions of dollars for public and private landowners (Oregon Department of Agriculture, 2001). Nationwide, the United States experiences annual losses of over $130,000,000.00 due to non-native species (Pimentel and others, 2000). Vegetative disturbance of natural ecosystems by geomorphic and anthropogenic processes affect soil substrate conditions, nutrient availability, canopy shading (solar influx), and riparian hydrology. The most abundant concentrations of invasive species are typically associated with disturbed zones that have been altered by human activity. As such, disturbed zones on the landscape act as primary conduits for the dispersal of non-native species (Pabst and Spies, 1998). Understanding the controls on spatial distribution of invasive plants in the context of disturbance regime is critical for designing effective watershed conservation and restoration plans.

The purpose of this research is to conduct a reconnaissance survey to delineate associations between geomorphic (landslides and floods) and anthropogenic disturbance (road construction, logging, and agriculture) regimes, and distribution patterns of invasive plant species in the Luckiamute Watershed of western Oregon (after Swanson et al., 1990). The Luckiamute is associated with a unique combination of geomorphic and land-use conditions that are well-suited for the study of causal factors that control spatial distribution of invasives in the region. The results of this preliminary work will form the basis of more extensive studies in the region and have potential use for development of larger scale predictive models of invasive plant dispersion.

PROJECT DISSEMINATION

All data and reports completed as part of this project were compiled and are being distributed via internet technologies (refer to URL: http://www.wou.edu/luckiamute), the Luckiamute Watershed Council newsletter, class content modules, and a watershed seminar series. The project web site is the primary information source for students and community stakeholders. All project spatial data were compiled into a GIS and are being distributed via a dedicated server housed at Western Oregon University (Table 1). Research results and related curriculum products will be disseminated by presentation at national geoscience meetings (e.g. Taylor, 2005) and in peer-reviewed publications.

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Taylor, S.B., 2005, Lithologic Controls on Watershed Morphology in the Central Oregon Coast Range: Towards Extrapolation of Tyee-Based Models to Other Bedrock Types – Mountain Rivers Session: Association of American Geographers, Abstracts with Programs, Annual Meeting, Denver.

Taylor, S.B., 2004, Geology of the Luckiamute River watershed, upper Willamette Basin, Polk and Benton Counties, Oregon: *in* Garono, R.J., Anderson, B.D., Harma, K., Buhl, C., and Adamus, P., Luckiamute / Ash Creek / American Bottom Watershed Assessment: Unpublished Technical Document, Luckiamute Watershed Council, Western Oregon University, Monmouth, Oregon, Appendix A – 19 p., available on line at <URL: http://www.wou.edu/las/natsci_math/geology/luckiamute/Appendix A Geology of Luckiamute River Watershed.pdf, updated June 2004.

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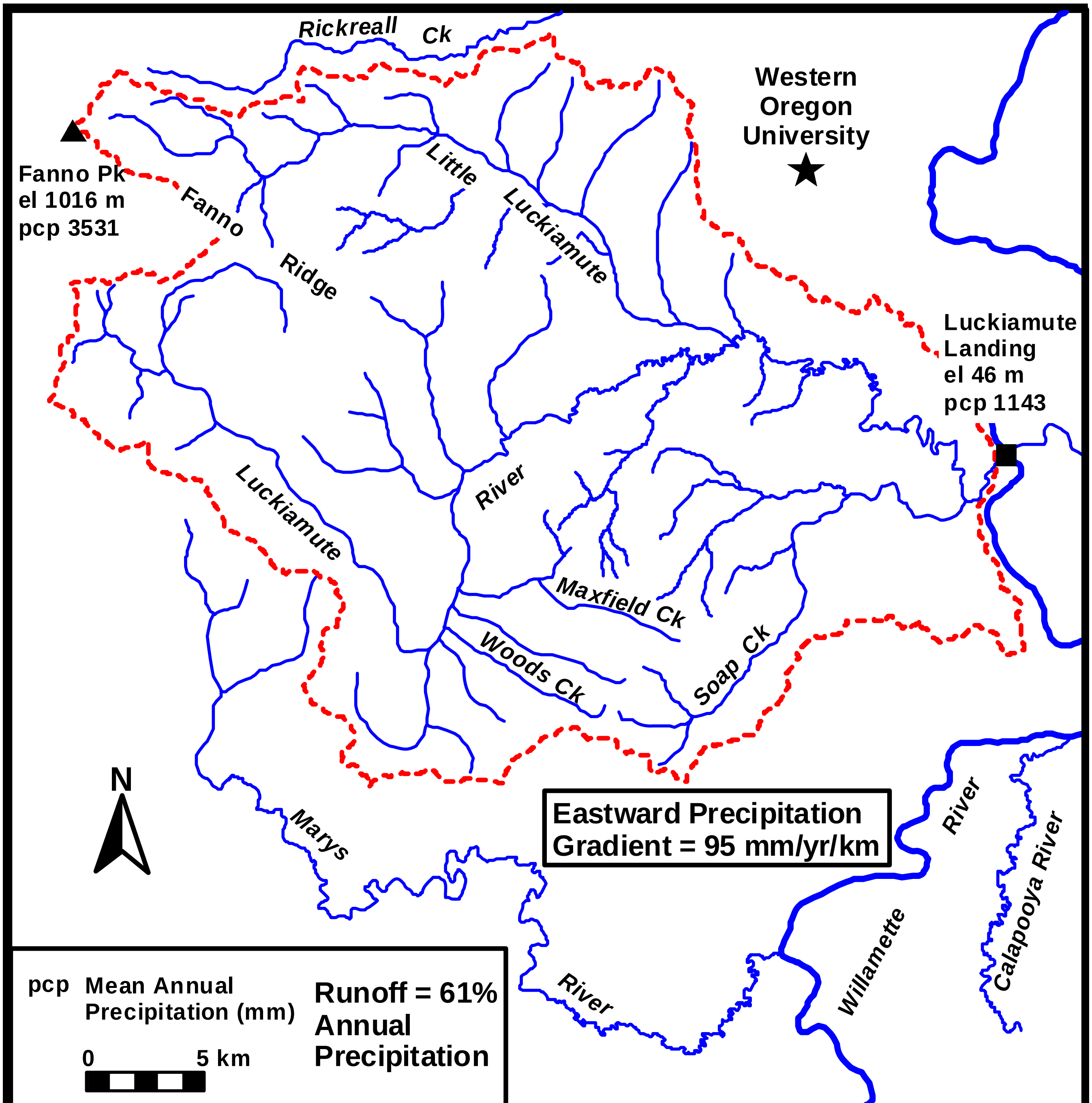
Dutton, B. and Taylor, S.B., 2005, Proposal for Invasive Plant Research: “Reconnaissance Survey of Japanese Knotweed in the Riparian Zone of the Luckiamute Watershed”, funding for $2000 awarded by the Northwest Invasive Weed Management Partnership Program.



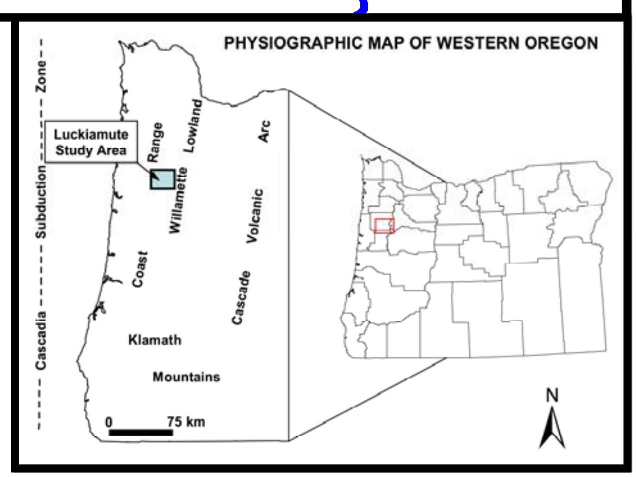


Figure 1. Location map of the Luckiamute Watershed study area.

Table 1. Summary of Luckiamute Watershed Project Deliverables (available online at www.wou.edu/luckiamute).

1. LUCKIAMUTE WATERSHED CONTEXTUAL LEARNING MODULES

ES322 Geomorphology - Introduction to Watershed Analysis - Luckiamute Basin
ES322 Geomorphology - Introduction to GIS and Luckiamute Basin
ES322 Geomorphology - Baker Ck Landslide Problem (Soap Creek Sub-basin)
ES322 Geomorphology - Helmick State Park Soil Survey Exercise (Luckiamute)
ES322 Geomorphology - Luckiamute Field Hydrology (part 1)
ES322 Geomorphology - Luckiamute Fluvial Hydrology (part 2)
ES322 Geomorphology - Luckiamute Watershed Field Portfolio Guidelines
ES473/573 Environmental Geology - Mountain Fir Groundwater Case Study
ES473/573 Environmental Geology - Luckiamute Watershed Assessment
ES476/576 Hydrology - Luckiamute Flood Hazards Lab

2. LUCKIAMUTE WATERSHED CLASS-RELATED FIELD GUIDES

Taylor (2004) Geology and Geomorphology of the Luckiamute Watershed
Taylor (2004) Field Guide to the Coffin Butte Landfill, Soap Creek Sub-basin
Taylor (2005) Hydrogeology of the Ash Creek Sub-basin

3. RELATED REPORTS AND PUBLICATIONS

Association of American Geographers-Mountain Rivers Session (Taylor, 2005)
Geology of the Luckiamute Basin (Taylor, 2004)
Luckiamute Watershed Assessment (Garono and others, 2004)
Luckiamute Watershed Assessment - Final Report (Garano and others, 2004)

4. LUCKIAMUTE GIS DATA COMPILATIONS

Bedrock Geology
- Bedrock - All Files (19.91 MB)
- Luckiamute Bedrock Geology (632.6 KB)
- State Geology (11.27 MB)
- Tyee Landscapes - Oregon Coast Range (106.0 KB)
- Willamette Valley Geology (7.92 MB)

Cultural and Geographic Data
- Benton County Taxlots (5.80 MB)
- Cultural-All Files (35.60 MB)
- Luckiamute Cultural Features (4.09 MB)
- State Features (2.51 MB)
- Polk County Taxlots (23.19 MB)

5. LUCKIAMUTE GIS DATA COMPILATIONS (con.t.)

CLAMS Coast Range Watershed Data
- Coast Range 6th-7th Field Basins (10.28 MB)
- Coast Range Streams (mideast section) (16.72 MB)
- Coast Range Streams (midwest section) (44.45 MB)
- Coast Range Streams (northeast section) (26.74 MB)
- Coast Range Streams (north section) (52.14 MB)
- Coast Range Streams (south section) (40.21 MB)
- Coast Range Streams (Umpqua section) (36.50 MB)

Geomorphology and Surficial Geology
- Debris Flow Hazards (Polk,Marion,Benton) (4.79 MB)
- Geomorphology-All Files (18.08 MB)
- Luckiamute Geomorphology (2.14 MB)
- Missoula Flood Maps (4.22 MB)
- Regional Physiography (428.1 KB)
- Willamette Surficial Geology (O'Connor et al., 2001) (6.44 MB)

Groundwater and Hydrogeology
- Luckiamute Groundwater Data (12.17 MB)

Soils
- Luckiamute Soils Data - Polk and Benton Counties (8.34 MB)

Surface Water Hydrology
- Luckiamute Surface Hydrology / Stream Channels (15.20 MB)

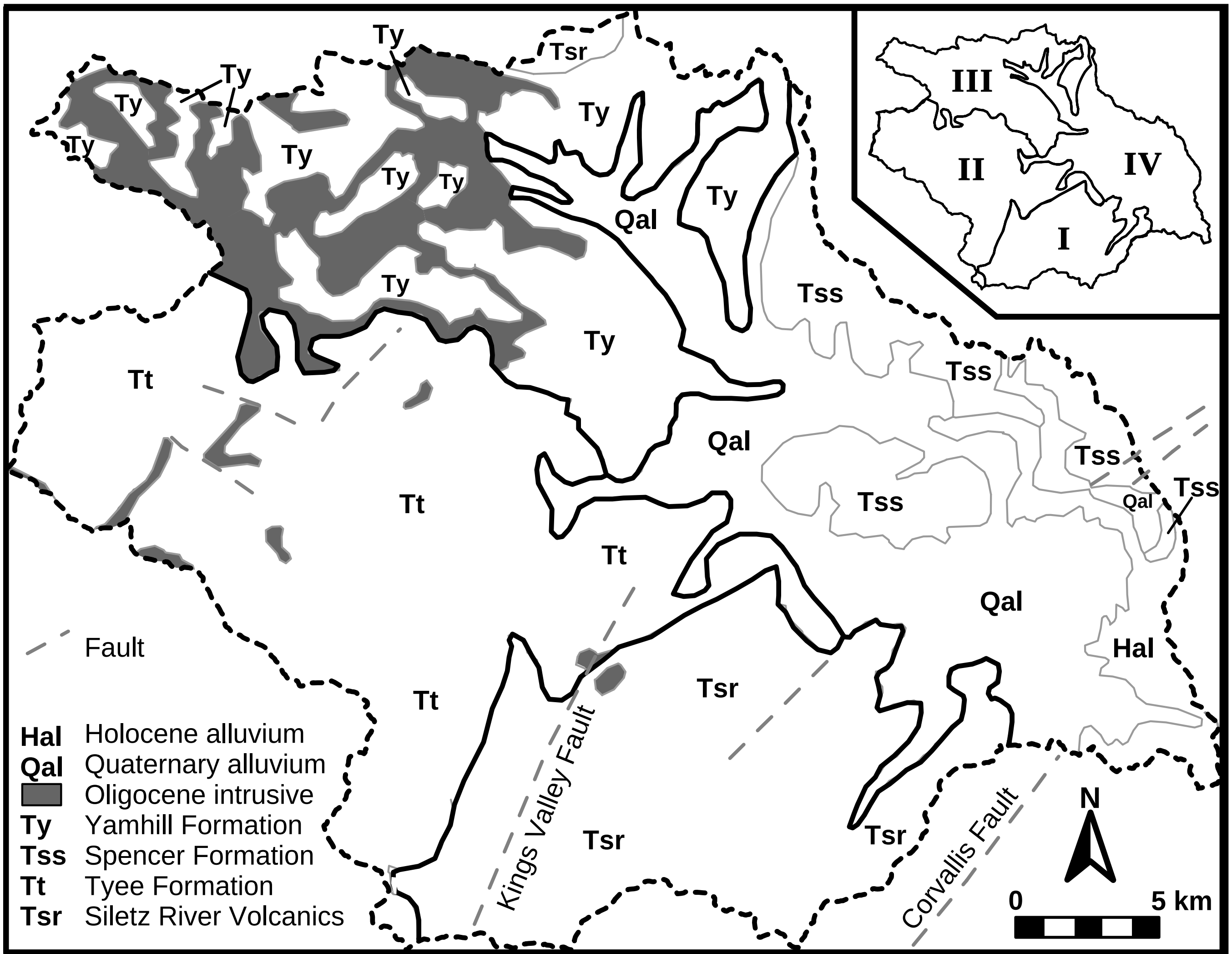
Topography / Elevation Models
- Luckiamute Topography / Contour Maps (56.43 MB)

Tyee Landscape Analysis
- Tyee Landscape Analysis - Test Watersheds (22.17 MB)

Vegetation
- Luckiamute Vegetation (24.03 MB)

Water Quality
- Luckiamute Water Quality (503.0 KB)

Figure 2. Western Oregon University Earth Science students actively engaged in Luckiamute Watershed learning and research modules.



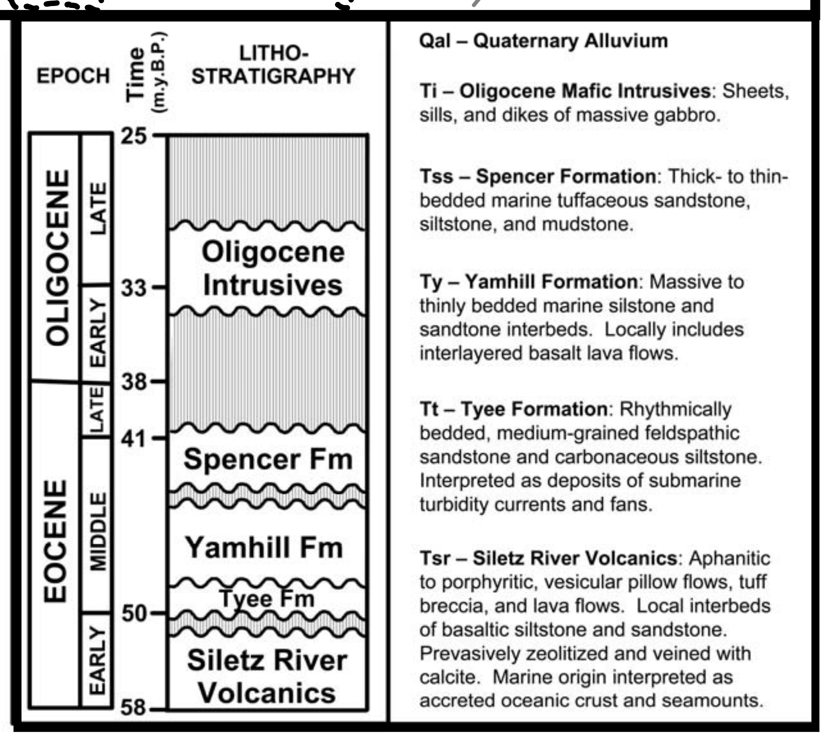
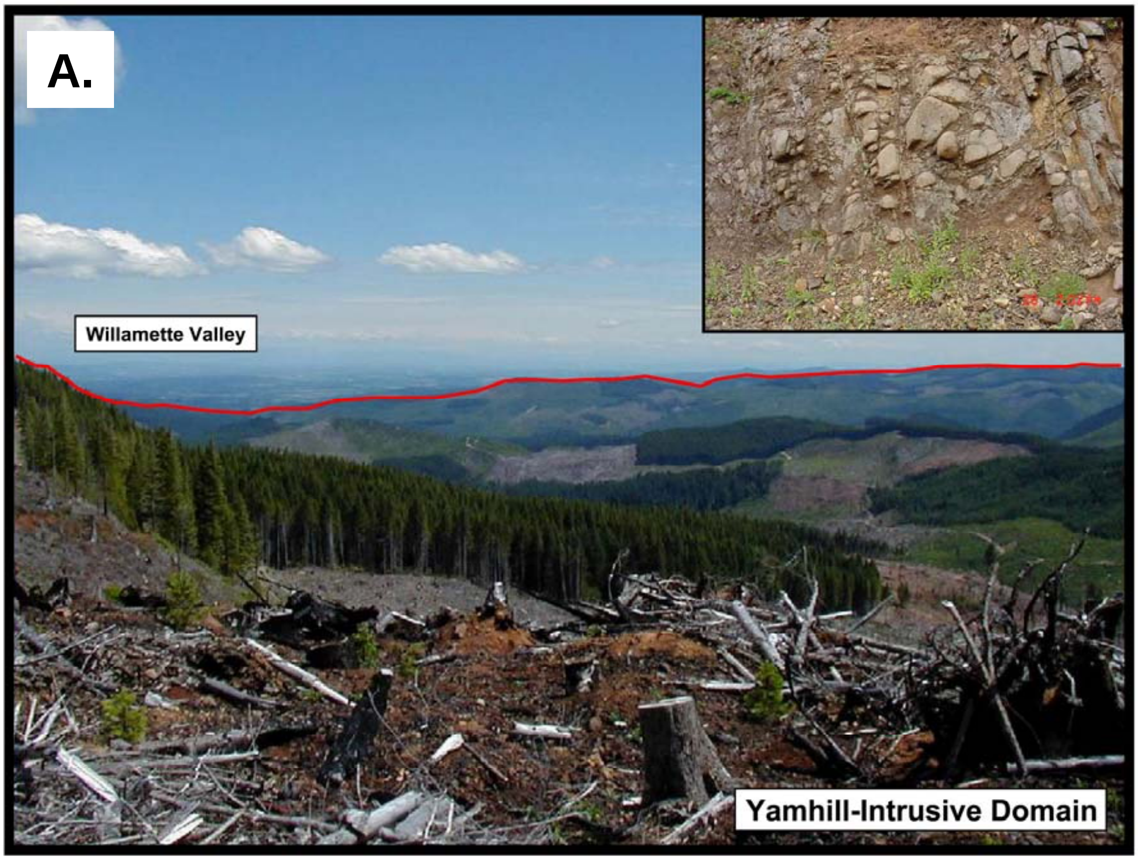


Figure 3. Bedrock geology of the Luckiamute study area.



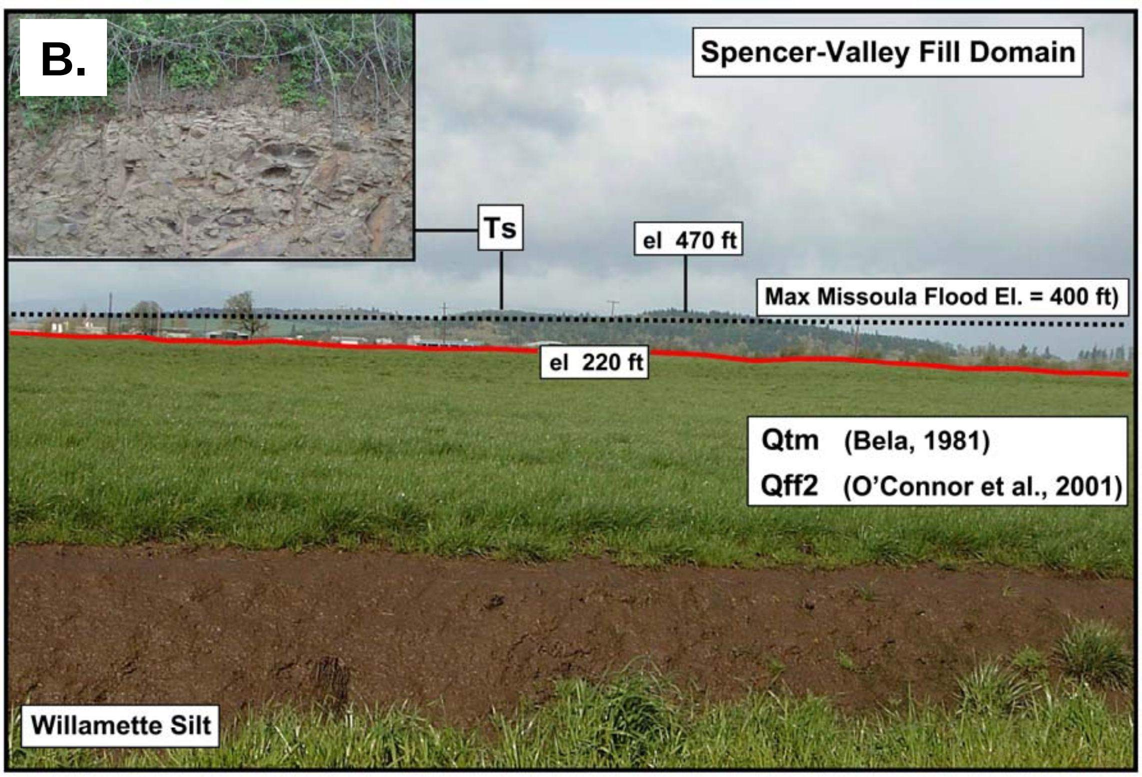


Figure 4. A. Photo showing western portion of the Luckiamute Watershed, upland landscape typical of the Yamhill-Intrusive domain. B. Photo showing eastern, lowland portion of the Luckiamute Watershed, Spencer-Valley-Fill domain.

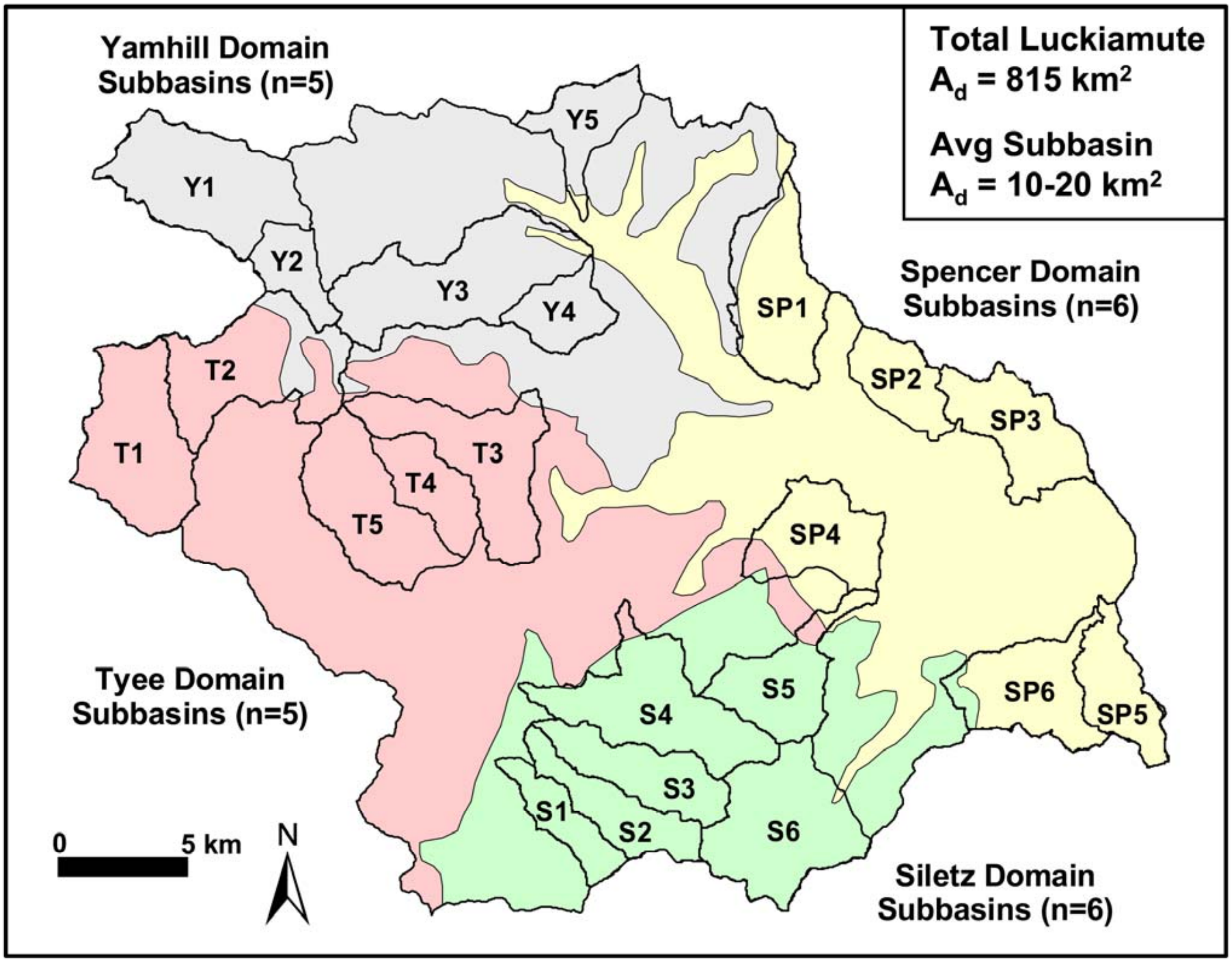


Figure 5. Location map showing fifth-field sub-basins selected for comparative geomorphic analysis in the Luckiamute Watershed.

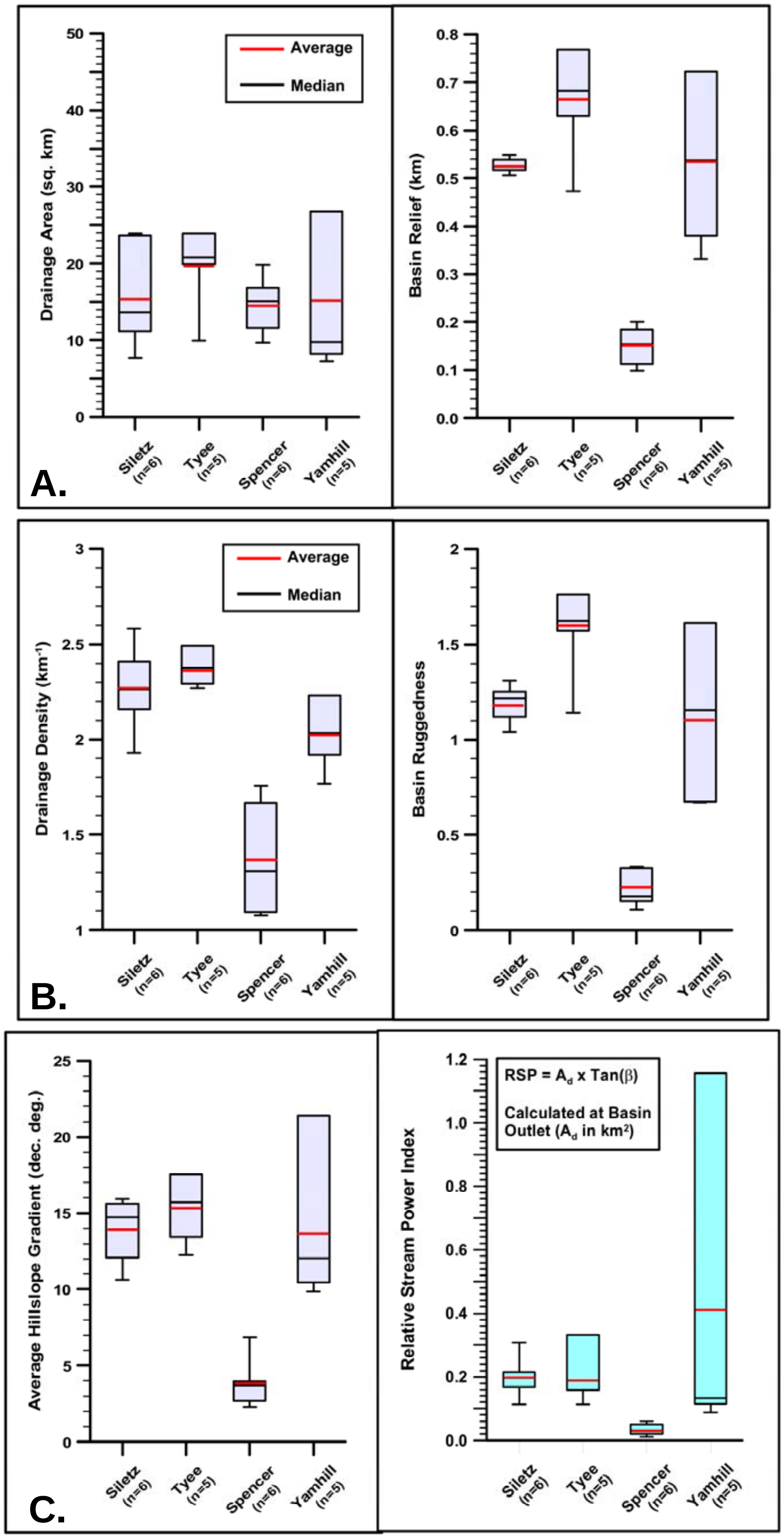


Figure 6. Results of comparative morphometric analysis of fifth-field sub-basins in the Luckiamute Watershed. Results show that the Tyee domain is associated with the steepest, most rugged high-relief landscape, whereas the Spencer is at the opposite end of the spectrum.

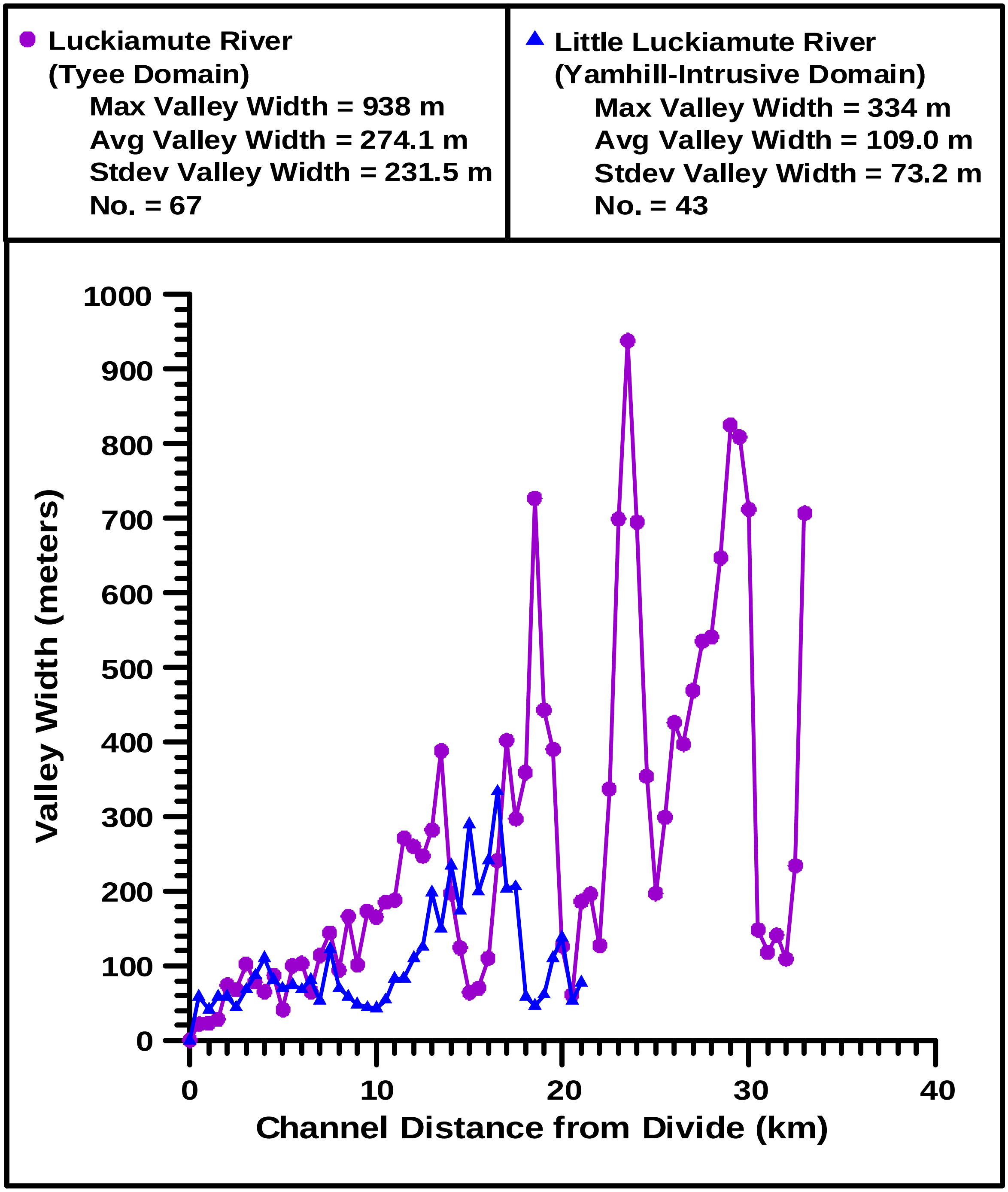


Figure 7. Plot of valley width (m) vs. channel distance from drainage divide (km) for the Luckiamute and Little Luckiamute tributaries, Tyee and Yamhill lithospatial domains, respectively.

Figure 8. A. Photo showing an under-capacity, bedrock channel reach along the Little Luckiamute tributary, Yamhill-Intrusive domain. B. Photo showing gravel-dominated reach along the main stem of the Luckiamute, Tyee domain.

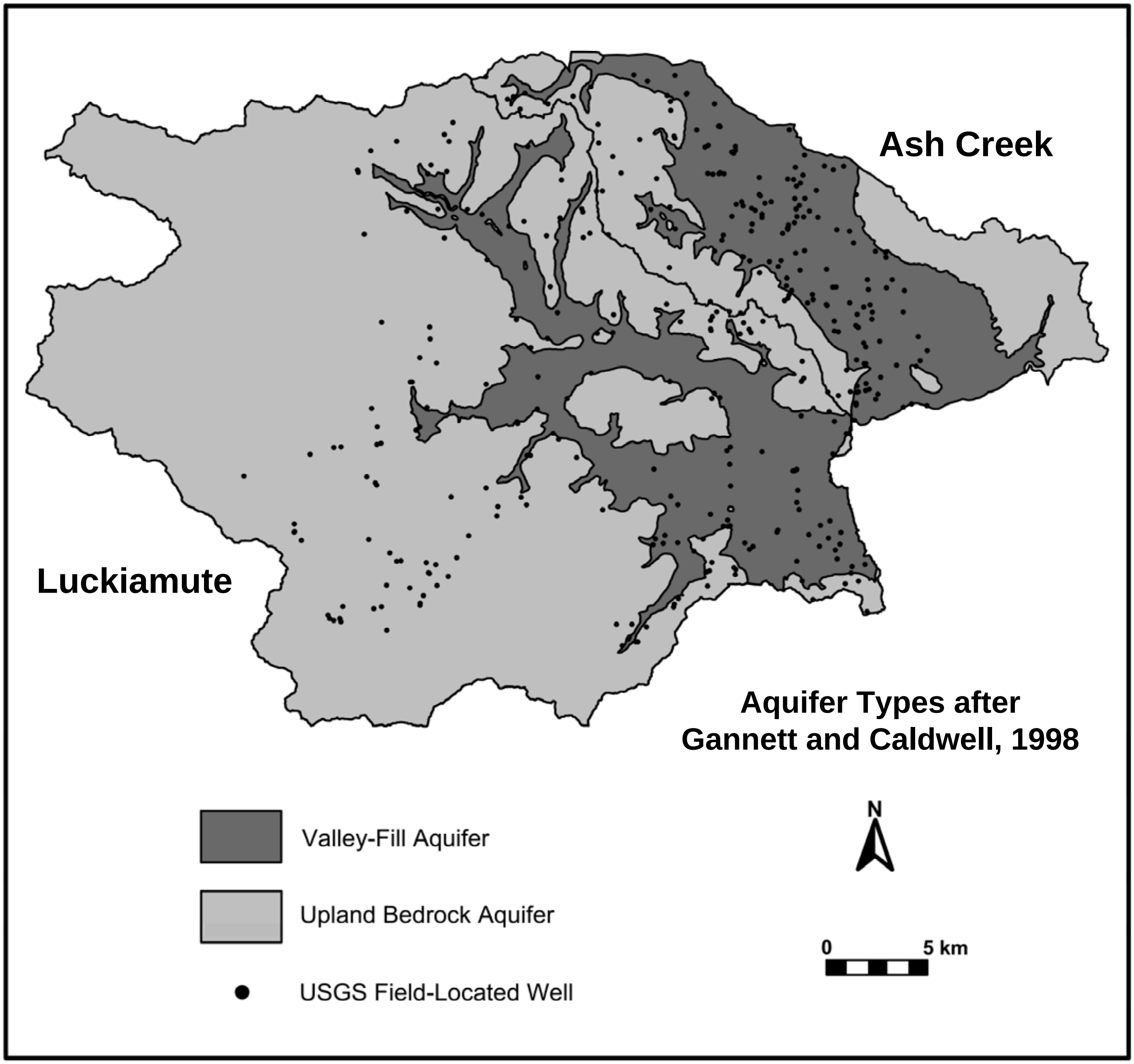


Figure 9. Aquifer type distribution in the Luckiamute-Ash Creek subbasins (after Gannett and Caldwell, 1998).

Table 2. Results of Luckiamute Well Survey (from U.S. Geological Survey Located Wells).

Surface Geology	Aquifer Unit	No. Wells	Min Depth (ft)	Max Depth (ft)	Avg Depth (ft)	Avg Deep (ft)	Avg DTW (ft)	Avg.# Specific Capacity (gpm/ft)
Qal – Holocene Alluvium	Basement Confining (Spencer Formation)	17	182	485	276	100	18	59.9
Qs – Willamette Silt	Basement Confining (Spencer Formation)	62	183	420	249	128	20	59.9
Ti – Oligocene Intrusives	Upland Bedrock (Tertiary Intrusives)	2	665	680	673	189	44	N/D
Tsr – Siletz River Volcanics	Upland Bedrock (Siletz River Volcanics)	42	235	1160	453	169	36	1.1
Tss – Spencer Formation	Upland Bedrock (Spencer Formation)	27	185	602	326	120	49	59.9
Tt – Tyee Formation	Upland Bedrock (Tyee Formation)	30	283	750	364	104	25	N/D
Ty – Yamhill Formation	Upland Bedrock (Yamhill Formation)	16	265	750	476	149	45	0.3
Luckiamute Watershed Summary		196	182	1160	402	137	34	

* Min Depth = minimum total well depth (feet), Max Depth = maximum total well depth (feet), Avg Depth = average total well depth (feet), Avg Deep = average well deepening (feet), Avg DTW = average depth to water from surface (feet)

#Specific capacity = well pumping rate (gallons per minute) divided by feet of drawdown (data from Caldwell, 1993 for Ash Creek subbasin)

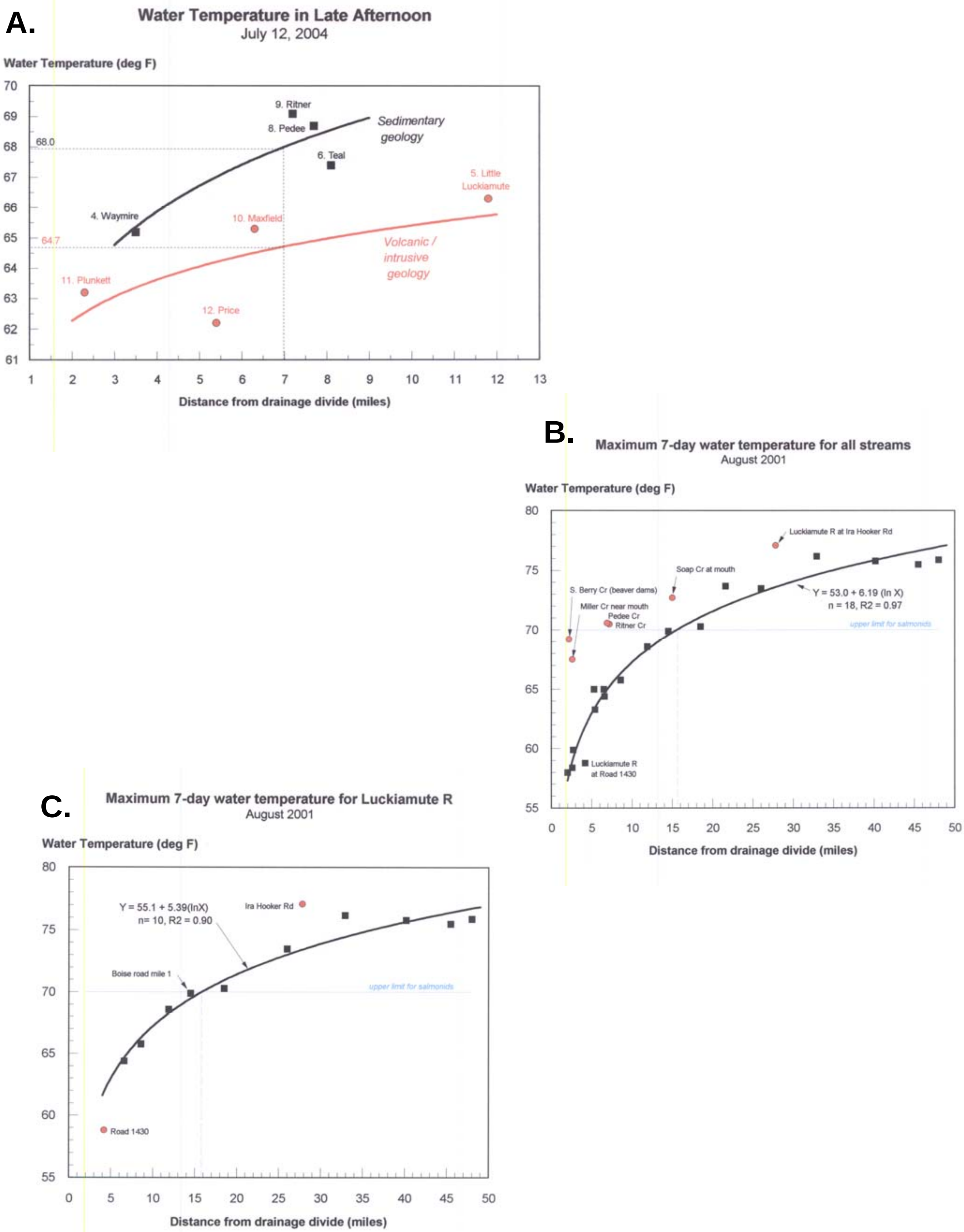


Figure 10. Results of stream temperature surveys along the Luckiamute and Little Luckiamute tributaries. A. Results from temperature sampling of the Tyee and Siletz lithospatial domains. B. and C. Results of 7-day August 2001 temperature survey by the Oregon Dept. of Environmental Quality (Andrus, 2004, personal communication).

Determining Spatial and Temporal Variability of Groundwater Nitrate in the Southern Willamette Valley, OR

Basic Information

Title:	Determining Spatial and Temporal Variability of Groundwater Nitrate in the Southern Willamette Valley, OR
Project Number:	2005OR64B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Oregon
Research Category:	Ground-water Flow and Transport
Focus Category:	Nitrate Contamination, Management and Planning, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	Roy Haggerty

Publication

Determining Spatial and Temporal Variability of Groundwater Nitrate in the Southern Willamette Valley, OR

Principal Investigator: Roy Haggerty
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Submitted to IWW (formerly CWESt)
February 14, 2006

EXECUTIVE SUMMARY

The Southern Willamette Valley (SWV) of Oregon has recently been designated a Groundwater Management Area (GWMA) due to concerns over high groundwater nitrate concentrations. As a GWMA, remedial practices must be implemented and groundwater monitoring must occur to determine if and when change occurs. We examined temporal and spatial variability of groundwater nitrate for the SWV with the objective of determining if seasonality exists. Seasonal fluctuations can complicate trend detection in groundwater monitoring, and thus it is important that baseline seasonal data is collected.

We determined if seasonal variability is present in the SWV by creating a monitoring network of 19 wells which we sampled for 15 months. Seasonal fluctuations of several mg/L were observed in nearly all wells sampled. Although network-wide seasonal trends were not statistically significant, our results indicate that the highest concentration months also generally have the highest rainfall, while the lowest concentration months have the least rainfall. Additionally, we found that of the two major hydrogeologic units for the study area (the Willamette Silt and the Willamette Aquifer) have statistically significant differences in concentration and variability. These differences are largely attributable to differences in land use and physical properties of the two units.

A hydrologic model was created to examine nitrate leaching in the SWV and to determine how land use change is likely to affect groundwater nitrate concentrations. Results from the model are largely consistent with observed results and thus it is being used to further analyze several alternative future scenarios. Best Management Practices being examined in the future scenarios include decreases in fertilizer, irrigation, and changes in crop types. Complete results will be available in Glenn Mutti's MS thesis and will also be posted to the web at the PI's website, http://science.orst.edu/~haggertr/WS/.

PROJECT DESCRIPTION & RESULTS

The objectives of this project were to determine if temporal and spatial variability are present in groundwater nitrate in the Southern Willamette Valley (SWV) of Oregon, and to model nitrogen loading and leaching related to land use for the SWV. A brief summary of our findings is included in this report; complete findings will be available in the MS thesis of Glenn Mutti (expected completion date March/April 2006) and will be posted to the web.

The SWV has regionally high groundwater nitrate concentrations (as documented by Eldridge (2003); Aitken et al. (2003); and Vick (2004)) and has been designated a Groundwater Management Area (GWMA) by the Oregon Department of Environmental Quality due to concerns about public health. Though several studies have examined the spatial distribution of groundwater nitrate concentrations, no study has examined monthly fluctuations in concentration for the SWV. Monthly studies examining vadose leachate for the Willamette Valley indicate that a strong seasonal trend is present for nitrate, with high concentration vadose water being purged from the root zone during rainy fall and winter months (Faega 2004, Shelby 1995). In this study we investigated if the seasonal pulse of high concentration vadose water causes temporal fluctuations in groundwater nitrate, filling a major data gap necessary for the design and implementation of a groundwater monitoring network in the SWV.

To determine temporal groundwater nitrate variability, we sampled from a network of 19 wells for 15 months (August 2004 – October 2005). Sample wells were selected from regions identified as significant with regard to spatial distribution, land use, hydrogeologic unit, and expected nitrate concentration (based on previous studies). After potential wells were selected, a well became a sample site if sampling permission was granted and it passed initial quality assurance standards. Quality assurance standards included a negative coliform bacteria test, well depth ≤ 50 ft, screening interval ≤ 15 ft, well log extant, and a drilling date within the last 30 years. Sampling protocols included an approximate purge time of 15 minutes, with samples collected after field parameters stabilized (field parameters collected most months include temperature, pH, conductivity, and dissolved oxygen).

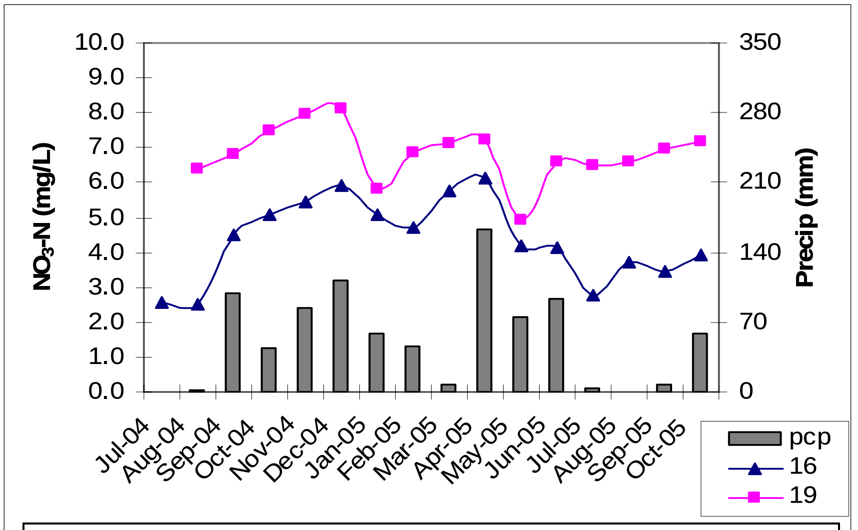

Figure 1: Seasonal fluctuations observed for two wells (16 and 19). Precipitation between sampling events is shown as bars.

Our results indicate that though network-wide seasonal nitrate differences are not statistically significant, seasonal nitrate fluctuations are considerable and generally are influenced by precipitation (see Figure 1). Most wells had higher nitrate

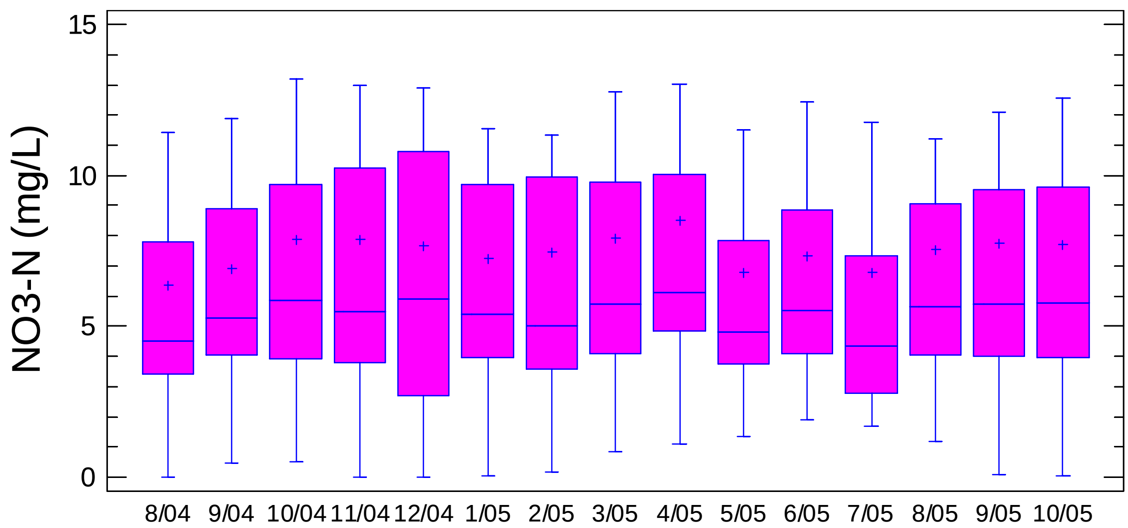

Figure 2: Monthly box and whisker plot for all data collected. "+" indicates the monthly mean values, the box bounds the 25th and 75th data percentiles, and the middle bar is the median. Whiskers extend to the farthest data point within 1.5 times of the box height. Median concentrations did not statistically differ (indicating no seasonality), but concentration fluctuations did generally follow precipitation

concentrations during months with heavy rain. In this study we found that April, the sampling month with the highest rainfall, had the highest nitrate concentrations for most wells. However, since our data were collected in an unusually dry winter, we believe that in an average year, concentrations would be highest in January or December, months that commonly have the highest precipitation. Months with the lowest median concentrations were July and August, which we expect to remain true most years (see Figure 2).

Several other trends were observed, including an apparent increase in groundwater nitrate concentrations with proportional increases in precipitation for months with recharge. Additionally, lower concentrations and temporal variabilites were found to exist in the Willamette Silt hydrogeologic unit, while a scaling effect between a well's median nitrate concentration and its variability was noted. The differences in variabilities are believed to largely be a function of land use, with higher intensity agriculture associated with higher concentrations, variabilities, and areas without the Willamette Silt. Wells having markedly different variabilities imply that different monitoring frequencies may be appropriate for different regions of the GWMA.

Implications of the seasonality observed at individual wells are numerous. From a homeowner's perspective, it is concerning because an annual well test may indicate suitable drinking water, but in reality concentrations may exceed the EPA public health limit (10 mg/L NO_3-N) for several months of a year. From a monitoring perspective, seasonal fluctuations will make long-term trend detection more difficult. Additionally, sample frequencies and dates will need to be well-planned if minimal seasonal noise is desired in the data set. Inferences that can be drawn from higher concentration months generally being high precipitation months is that vadose nitrate flushing has an impact on groundwater nitrate concentrations, and that at the present, average vadose nitrate concentrations are higher than groundwater concentrations. This implies that for groundwater nitrate concentrations to decline, land management practices need to change and the vadose zone will need to be flushed of much of its nitrate. The flushing of the vadose nitrate could take significant time (years to decades) because of the slow rate of diffusion from small soil pores.

Hydrologic modeling of the SWV was successful at showing areas where high leaching was likely to occur. Modeled results (see Figure 3) show that higher leaching generally occurs in areas overlying the exposed extent of the Willamette aquifer. Work continues in examining the impacts of Best Management Practices (BMPs) with present day land use and projected future land use (future land use data generated by Hulse et al. (2002)). BMPs being investigated include decreased fertilizer use, decreased irrigation, and changes in crop type. Finalized results will be available in Mutti's thesis and posted to the web.

The model used in this research is novel because it is the first hydrologic model of the SWV that examines nitrate transport. Additionally, outputs created from this model can be linked to a groundwater model recently developed for the SWV (Craner, 2006). Integrating the leaching data developed from this study with the groundwater model will allow hydrogeologists to gain a deeper understanding of the transport time and likely nitrate source regions for different parts of the aquifer. Combining these models should therefore yield an expected time frame for broad, aquifer-wide concentration changes due to BMP implementation. An expected time frame for regional change is valuable in determining expected monitoring costs and shaping monitoring objectives.

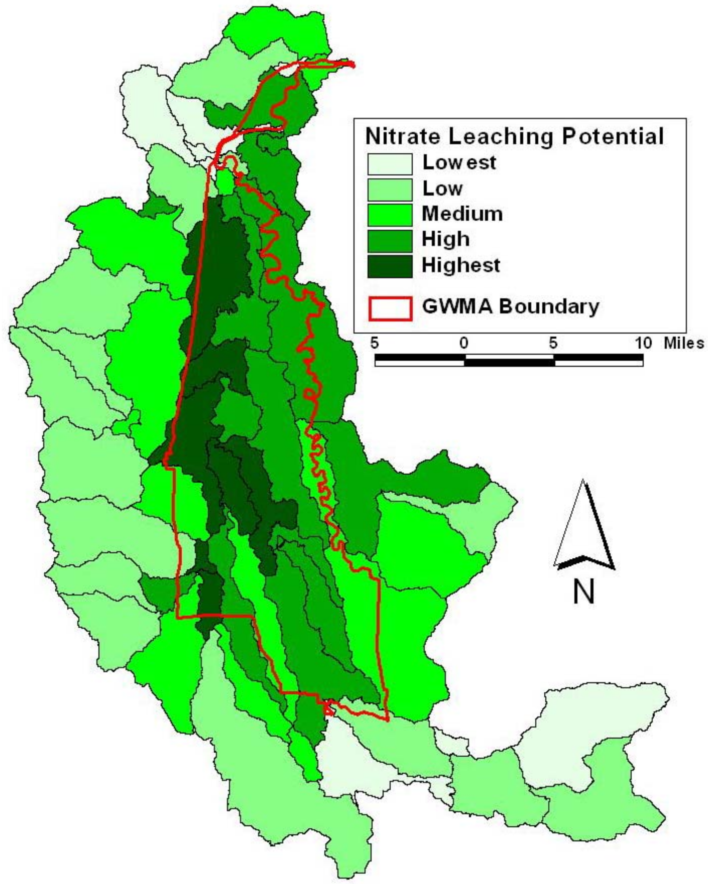

Figure 3: Modeled results showing areas with lower and higher nitrate leaching based on land management and soil types. The darkest green zones mostly overlie regions where the Willamette Aquifer is unconfined and hence more vulnerable to contamination.

Results from this study will act as a guide for the determining appropriate groundwater monitoring strategies for the GWMA. A presentation on results of this study was well-received by the GWMA committee and is expected to strongly influence the discussion regarding monitoring well installation locations at an upcoming GWMA technical advisory board meeting.

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Influence of Climate Change on Water Supply in the McKenzie River Basin: Analysis of Long-term and Spatial Hydrologic Data.

Basic Information

Title:	Influence of Climate Change on Water Supply in the McKenzie River Basin: Analysis of Long-term and Spatial Hydrologic Data.
Project Number:	2005OR65B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Oregon
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Water Quantity, Groundwater
Descriptors:	
Principal Investigators:	Anne W. Nolin

Publication

1. Jefferson, A., Nolin, A., Lewis, S., Payne, M. and Grant, G., Climate variability, snowmelt distribution and effects on streamflow in a Cascades watershed, to be submitted to Hydrological Processes.
2. Nolin, A.W. and C. Daly, Mapping at-risk snow in the Pacific Northwest, U. S. A., Journal of Hydrometeorology, in press.
3. Water Supply is on the rocks and that's okay Article in Salem Statesman-Journal, April 4, 2006
4. Global climate change may have a lasting impact on the Lane County landscape. Interview with Eugene Register-Guard, Sunday January 29, 2006.
5. Warmer winters may melt ski spots Article in The Oregonian, March 7, 2006
6. Global warming may melt away fun, study says Article in Seattle Times, March 8, 2006
7. Oregon snow may melt with increased warming Interview with KINK radio, Portland, Oregon, March 8, 2006
8. Warming could douse Oregon ski areas Article in Eugene Register-Guard, March 8, 2006

Influence of Climate Change on Water Supply in the McKenzie River Basin: Analysis of Long-term and Spatial Hydrologic Data

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Focus Category: WQN, HYDROL, GW, SW
Congressional District: 5th

Abstract

The snowmelt-dominated Cascade mountains provide critical water supply for agriculture, ecosystems, and municipalities. Watersheds draining the Cascades are home to over 3 million Oregonians. Recent analyses show that this region is particularly sensitive to current and projected climate warming trends. The focus of our research is the watershed of Clear Lake in the upper McKenzie River basin. This watershed, with an area of 239 km^2, has long-term records of streamflow, precipitation, and snowpack. Our overarching goal is to determine the timescales and degree of seasonal and inter-annual "memory" between precipitation inputs and streamflow outputs. The specific objectives of this work are therefore to:

1. Examine spatial variability in snow accumulation and melt, precipitation, evapotranspiration, and groundwater recharge in order to be able to quantify seasonal and year-to-year inputs to the hydrologic system;
2. Complete a seasonal and annual water balance for the Clear Lake watershed for wet, dry, and "normal" years;
3. Use long-term datasets to assess time lags between precipitation, snowmelt recharge, and streamflow response.

We use existing and newly compiled data sets to compute water balance, cross-correlations and regression modeling to improve the prediction of annual discharge and mean August discharge. We also analyze the data sets to identify secular trends in discharge in the Clear Lake watershed. Results show that generally, discharge, precipitation and SWE vary together throughout the period of record and among the 3 SNOTEL sites. There are clearly wet years, where all 3 parameters are above average at each of the sites and dry years, where all 3 parameters are below average. Temperature generally varies inversely with the hydrologic parameters, usually a year is cool & wet or warm & dry. For the four-year period of 2001-2004, discharge plus ET equaled 99.8% of precipitation in the Clear Lake watershed. On the annual time-scale, ET was 26% of precipitation. We developed a stepwise regression model for August discharge using four variables: precipitation accumulated at Santiam Junction by April 1st (P_{SJ41}, mm), the previous year's minimum discharge (Q_{min-1}, m^3/s), the previous year's winter temperature, and the April 1 SWE at Hogg Pass. When the fitted and validation datasets are combined, the overall R^2 is 0.78. The model predicts an average August discharge of 9.2 m^3/s for 2006, >60% of years in the 62 year period of record at Clear Lake. Both discharge and snow water equivalent show a model level of predictability using an El Niño index. In our examination of secular trends, the historical record suggests that minimum flows are declining as snowmelt occurs earlier. Earlier snowmelt causes the hydrograph to peak sooner in the spring, meaning that the recession from that peak to the beginning of fall rains occurs for a longer period of time and reaches a lower ultimate discharge. Although the declining minimum flows mean difficult management decisions, improved predictability of August streamflows will allow water resources managers to predict average August flow as early as April 1. This allows time to assess consequences of high or low flows and plan mitigation strategies if necessary.

Significance and Justification

The snowmelt-dominated Cascade mountains provide critical water supply for agriculture, ecosystems, and municipalities. Watersheds draining the Cascades are home to over 3 million Oregonians. Recent analyses show that this region is particularly sensitive to current and projected climate warming trends, specifically reduced snow accumulation and earlier spring melt, leading to a decline in summer streamflow (Service, 2004). By 2050, Cascade snowpacks are projected to be less than half of what they are today (Leung et al., 2004), potentially leading to major water shortages during the low-flow summer season. Snowpacks in western North America have declined over the past 50 years, primarily due to an increase in winter (Mote et al., 2005). These broad regional-scale characterizations identify climatic gradients as first-order controls on spatial variability in changing streamflow regimes, but the potential for other landscape controls, notably regional geology, to mediate this response has received much less attention.

This investigation was prompted by our previous research revealing that spatial patterns of summer streamflow in the Cascades exhibit significant differences between the geologically-distinct High and Western Cascade regions (Tague and Grant, 2004). A key control on streamflow differences between these two regions is the partitioning of water input between a fast-draining shallow subsurface flow network (Western Cascades) versus a slow-draining deeper groundwater system (High Cascades). In particular, we hypothesize that for the young volcanic terrains comprising the High Cascades, ground water storage is of sufficient magnitude to buffer potential changes in snowpack volume, hence summer streamflow, due to changing climate, as long as total annual precipitation remains roughly constant. However, we cannot produce accurate models of streamflow response to climate change and variability unless we have a realistic water balance that takes into account snowpack dynamics and spatial variability, and an understanding of time lags in the hydrologic system. Consequently, a necessary first step toward providing realistic model scenarios of future water supplies in Oregon is to understand the past and current behavior of the High Cascades hydrologic system on event, seasonal, and interannual timescales.

This research addresses two critical questions underlying the prediction of hydrologic response to future climate change. First, we identify and quantify key components of the water balance and how they vary across the landscape and through time using remote sensing and historical data. We also examine snowpack and groundwater storage and use time-series analysis to investigate how these reservoirs cause lags in the streamflow response to meteorological inputs.

The focus of our research is the watershed of Clear Lake in the upper McKenzie River basin (Figure 1). This watershed, with an area of 239 km^2, has long-term records of streamflow, precipitation, and snowpack, and is the hub of on-going research on snowmelt response to wildfire (Nolin) and groundwater recharge in young basalts (Jefferson and Grant). Furthermore, the watershed includes substantial areas of typical High Cascades geology, with extensive low-relief lava flows less than 5000 years old, as well as deeply dissected Western Cascades landscapes. Results and methodologies developed from this project may be broadly applicable to the Oregon Cascades.

Clear Lake forms the headwaters of the McKenzie River, which is the source of water and electricity for the city of Eugene, a major recreational economy, and superb salmon and bull trout habitat. Although the Clear Lake watershed occupies only 0.8% of the Willamette basin, it contributes almost 2% of late summer discharge to the entire Willamette River (measured at Portland harbor).

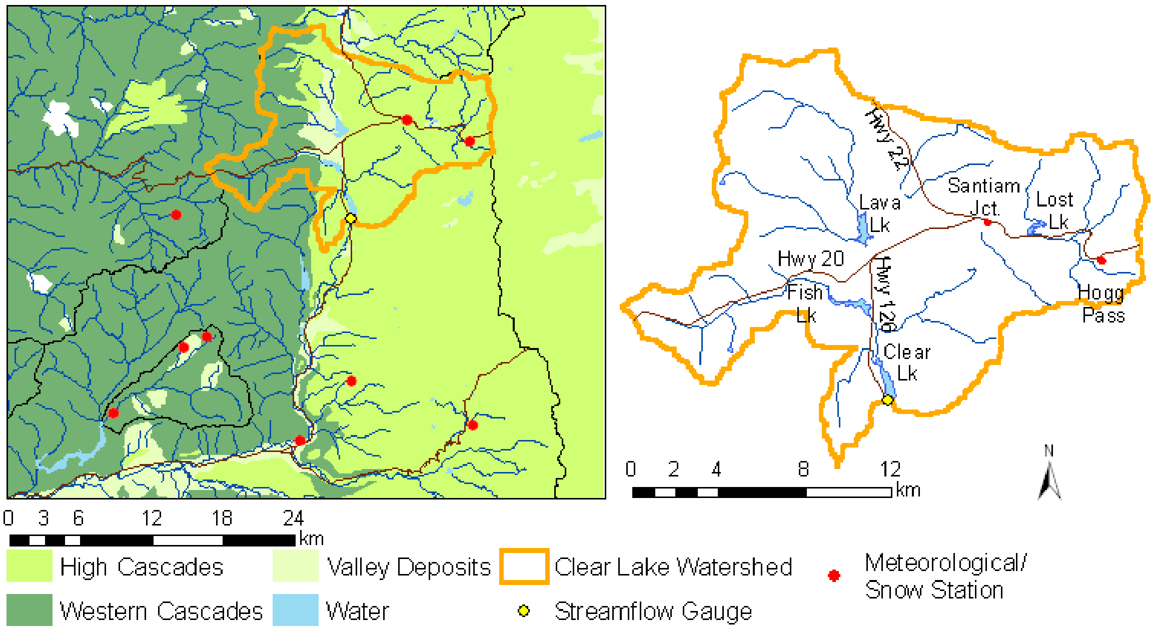

Figure 1. Location map showing Clear Lake watershed, Cascade geology, and meteorological stations.

Nature, scope, and objectives

The goal of this investigation is to analyze historic hydrologic responses to climate variability in the Clear Lake watershed to guide long-term prediction of hydrologic response to climatic change. Our overarching goal is to determine the timescales and degree of seasonal and inter-annual "memory" between precipitation inputs and streamflow outputs. In particular, our aim was to determine whether system memory of wet or dry years persists beyond the year in which the precipitation surplus or deficit occurred. The objectives of this work are therefore to:

4. Examine spatial variability in snow accumulation and melt, precipitation, evapotranspiration, and groundwater recharge in order to be able to quantify seasonal and year-to-year inputs to the hydrologic system;
5. Complete a seasonal and annual water balance for the Clear Lake watershed for wet, dry, and "normal" years;
6. Use long-term datasets to assess time lags between precipitation, snowmelt recharge, and streamflow response.

Methods

Selection and compilation of datasets

Of the available regional meteorological stations, SNOTEL sites provide the longest continuous records of rainfall, snow water equivalent (SWE) and temperature. Since elevations in the Clear Lake watershed range from 918 m at the outlet of Clear Lake to 2051 m on Mount Washington, three sites were selected to be representative of this range. Approximately ~20% of the watershed has an elevation higher than Hogg Pass (1451 m), 63% is higher than Santiam Junction (1143 m), and 83% is higher than Jump Off Joe (1067 m), which lies <3 km west of the Clear Lake watershed. The long-term (>20 year) data sets derived from measurements at SNOTEL sites were used to explore the influence of variation in meteorological parameters on Clear Lake discharge.

For each of the four parameters of interest, annual statistics were compiled from measured daily values as described below. Precipitation and SWE were complied from SNOTEL data for water years 1979-2005 at Santiam Junction and Jump Off Joe and water years 1980-2005 at Hogg Pass.   Mean annual precipitation was calculated from measured daily precipitation (includes both rain & snow). Total annual snowfall, reported as snow-water equivalent (SWE), was calculated from measured daily SWE. Temperature was compiled from SNOTEL measured daily temperature maxima and minima for water years 1985-2003 at Santiam Junction and Jump Off Joe and water years 1983-2005 at Hogg Pass. The number of days per year when the maximum temperature remained below zero was used as an index of the “coldness” of the winter. Discharge for the McKenzie River at the outlet of Clear Lake is reported as a daily value by the USGS. An annual mean value was calculated for water years 1978-2005.

To facilitate comparison of the data, the distribution of annual values for each parameter was normalized using the z-score transformation. Discharge, precipitation and SWE were normalized for the period 1980-2005 and temperature was normalized for the period 1985-2003. The z-score for a parameter indicates how far and in what direction the parameter deviates from the distribution's mean, expressed in units of its distribution's standard deviation where:

z-score = (annual value – mean of annual values) / standard deviation of annual values

Plotting z-scores rather than absolute values results in four time series each having a zero mean and unit standard deviation, allowing for easy comparison of the data.

Water Balance

A simplified water balance for the Clear Lake watershed was constructed for the 2001-2004 water years to examine the magnitudes and seasonal variations in water fluxes and stores. Discharge was calculated at the USGS gage, and precipitation and SWE at the median basin elevation (1215 m) were derived by linear interpolation from values at Jump Off Joe and Hogg Pass. Christina Tague (San Diego State University) supplied us with basin-average evapotranspiration (ET) calculated using RHESSys, a physically-based hydro-ecological model previously calibrated for the Clear Lake watershed (Tague and Band, 2004; Tague et al., in review).

Cross-correlations

Daily time-series of discharge, precipitation, snow water equivalent (SWE), and recharge (rain + snowmelt) were normalized to their daily means, and auto- and cross-correlations were computed following the methods described by Box and Jenkins (1976). A similar analysis was conducted for annual time-series.

Modeling

A predictive model of mean August discharge was developed using stepwise regression in SAS 9.1. The model was based on data from the 1984-2003 water years, and 39 parameters were tested as potential predictors (Table 1). Stepwise selection of parameters proceeded until all variables in the model were significant at the 0.05 level and no other variables met the 0.05 significance level for entry into the model. Colinearity was minimized by manual elimination of strongly correlated variables. The resultant model was tested with data from 1979-1983 and 2004-2005.

Correlations with Major Climate Indices

We examined and quantified the relationships between two major climate indices that have been correlated with streamflow in the Pacific Northwest: El Niño/Southern Oscillation Index the Pacific Decadal Oscillation (Beebee and Manga, 2004). We use the Niño 3.4 Index of sea surface temperature (Trenberth and Stepaniak, 2001) and the Southern Oscillation Index of surface pressure (NOAA, 2000) over the period 1978-2004 to explore correlations between El Niño/Southern Oscillation (ENSO) with discharge. The Pacific Decadal Oscillation (PDO) data set is from the University of Washington (Mantua, 2001). We computed correlations between these climate indices and mean annual discharge and mean August discharge using Pearson's linear regression. Individual monthly values of the indices were used rather than seasonal aggregates to better understand the time lags between discharge and the climate indices.

Results

Hydroclimatology

Generally, discharge, precipitation and SWE vary together throughout the period of record and among the 3 SNOTEL sites. There are clearly wet years, where all 3 parameters are above average at each of the sites (1982, 1997, 1999, 2002) and dry years, where all 3 parameters are below average (1987, 1991, 1992, 1994, 2001, 2003, 2005). Temperature generally varies inversely with the hydrologic parameters, usually a year is cool & wet or warm & dry. Years when temperature significantly diverges from the trend, warm wet years such as 1996, or cool dry years such as 1986, may be attributed to larger climate signals such as ENSO or PDO.

The watershed receives a mixture of rain and snow at all elevations. At Hogg Pass, 56% of annual precipitation accumulates as snow, whereas at Santiam Junction it is 37%, and at Jump Off Joe it is 25%. Mean discharge at Clear Lake is strongly correlated with precipitation at all three sites ($r>0.88$), but only at Hogg Pass is there a strong correlation between snow water equivalent (SWE) and mean discharge ($r=0.74$). SWE increases with elevation, and the date peak SWE is reached is later at Hogg Pass than at the lower elevation sites. However, the amount of peak SWE and the date at which it is reached is only poorly correlated for any individual site.

The autocorrelation of Clear Lake discharge shows a slow recession, or the rate at which peak flows diminish to low flows. This slow recession is characteristic of groundwater-fed streams. Discharge is strongly positively auto-correlated ($r>0.5$) for lags of up to 20 days, as opposed to the <7 days typical of streams without extensive groundwater. There are also moderate cross-correlations between Clear Lake discharge and SWE at the 3 SNOTEL sites. The peak cross-correlations occur at 74 to 82 day lags, which probably represents the average time from snowfall to snowmelt. Elevational differences are also apparent in the cross-correlation signal. For short lags, there is a moderate positive correlation between Hogg Pass SWE and discharge, because snow at high elevations may reflect rain at lower elevations, which, in turn, can lead to increasing discharge. There is no correlation between Santiam Junction or Jump-Off Joe SWE and Clear Lake discharge at short lags.

Water Balance

For the four year period of 2001-2004, discharge plus ET equaled 99.8% of precipitation in the Clear Lake watershed (Figure 2). On the annual time-scale, ET was 26% of precipitation, which is almost exactly the same as the ET portion of a 30-year water balance calculated for the adjacent Smith River watershed (Jefferson and Grant, 2003) and within the range of values reported for Western Cascade forests (Jones and Post, 2004). The near perfect match of the annual inputs and outputs and the concordance of ET estimates with regional values lend support to the seasonal water balance calculations despite the simplicity of the methods.

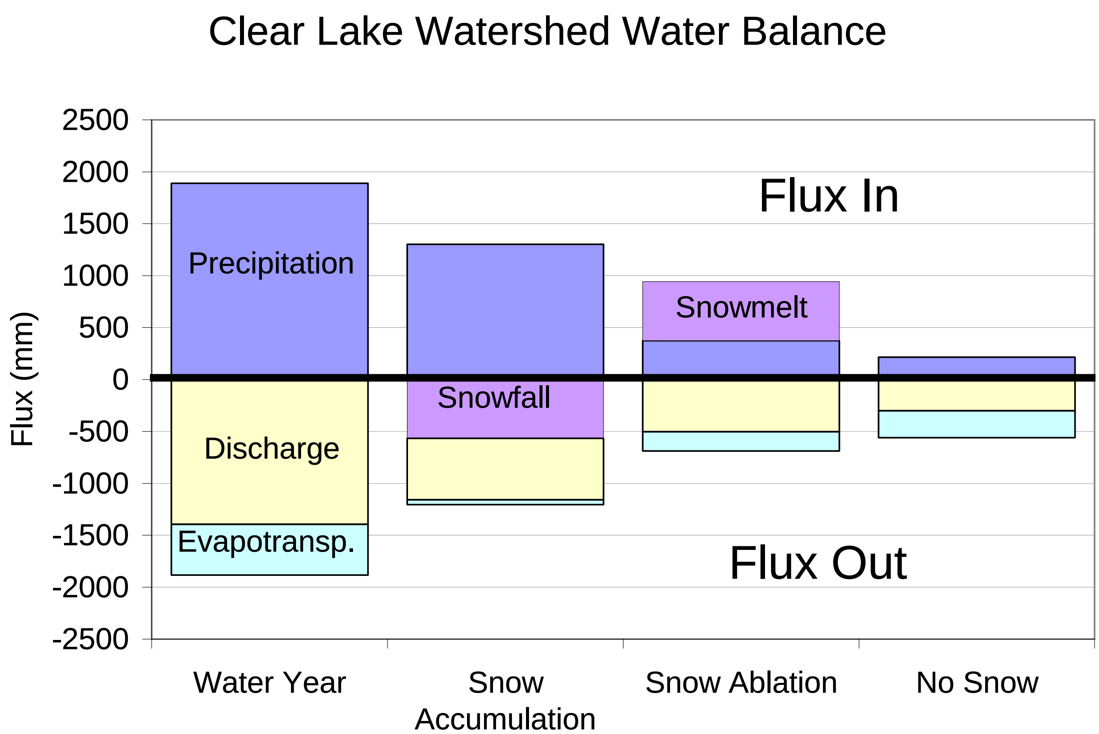

Figure 2. Water balance for the Clear Lake watershed.

We divided the year into three seasons based on the status of the snowpack. November through March constitute the snow accumulation season; April through June are the snow ablation season; and July through October are the no snow season. In the snow accumulation season, 44% of precipitation is stored as snowpack, 46% is accounted for as discharge, and 4% is lost to ET. The remaining 7%, ~100 mm, probably goes to replenishing the soil moisture supply and groundwater storage. In the snow ablation season, ET loss accounts for 49% of incoming precipitation. Abundant snowmelt supplies enough water to account for the discharge and to provide ~250 mm to groundwater storage. In the no snow season, discharge and evapotranspiration are 250% of precipitation, and groundwater storage diminishes to sustain streamflow and supply water to vegetation.

Inter-annual variability

Several analyses indicate an inter-annual memory in the watershed as a result of the High Cascades groundwater system. There are moderate cross-correlations between the previous year's precipitation and discharge at Clear Lake (r_{max}=0.52 for Hogg Pass).

This cross-correlation is higher than either the discharge or precipitation autocorrelation at a 1 year lag. Both the discharge autocorrelation and the cross-correlation are stronger than those for a nearby watershed without an extensive groundwater system.

Plotting z-scores of precipitation versus those for discharge shows that the groundwater system buffers discharge from inter-annual fluctuations in precipitation (Figure 3). This buffering is shown most clearly when a dry year follows several wet years, or vice versa. For example, 1998 was somewhat drier than average, but discharge was above average following two wet years. Similarly, 1995 was wetter than average, but discharge was just below average following a dry year. In the case of persistent drought (1990-1992) or wet years (1982-1984), the z-score of the discharge falls in line with the prevailing precipitation conditions.

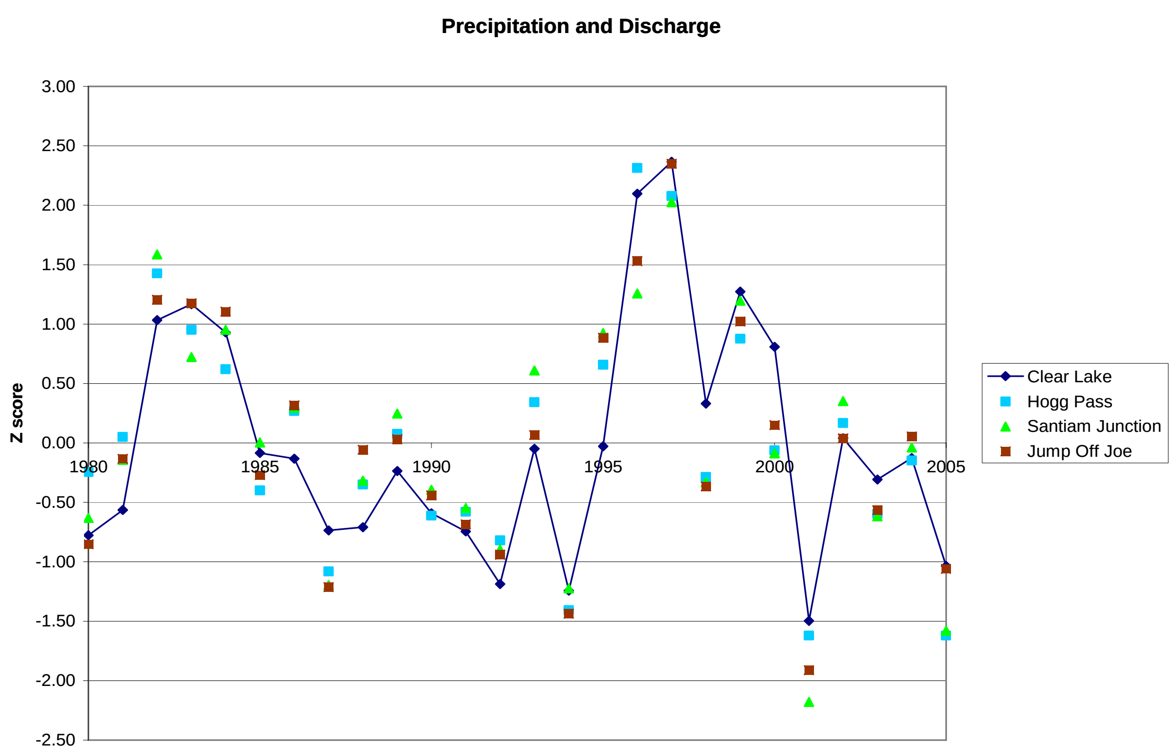

Figure 3. Annual precipitation for the three SNOTel stations and discharge for Clear Lake. Values are shown as z-scores.

Secular trends

Investigation of long-term trends in climatic and hydrograph parameters suggests that inter-annual variability masks potential trends in precipitation and SWE data derived from the <30 year SNOTEL record. The only parameter to exhibit a statistically significant relationship with time was the date of last snow cover at Santiam Junction. There was a weak trend toward earlier loss of snow cover at this site, not exhibited at either the lower or the higher elevation sites. The elevation and temperature regime of Santiam Junction may be particularly susceptible to warming-induced loss of snow as shown in Nolin and Daly (2006) in which such lower elevation snowpacks were shown to be highly temperature sensitive. In these areas, the winter precipitation regime may be shifting from a snow-dominated regime to one that is increasingly dominated by rainfall.

The discharge record for Clear Lake is continuous since 1948 and also has data for 1913-1915. Using only this longer dataset, preliminary analysis suggests that there are some secular trends, although the record is still dominated by inter-annual variability. A trend toward earlier snowmelt is indicated by the hydrograph temporal centroid. The temporal centroid is the day of the water year when half of the annual discharge has occurred, and has been used as an indicator of climate change throughout the mountainous West (Stewart et al., 2005). A best fit line through the data suggests that the temporal centroid has moved earlier in the year by 14-15 days since 1950 and 23-24 days since 1913. This trend is statistically significant at the 95% confidence level.

Earlier snowmelt also seems to be affecting the minimum discharge from Clear Lake. Minimum discharge generally occurs between September and November, and is a function of the year's precipitation, timing of snowmelt, timing of the fall rains, and, possibly, the aquifer storage. There is a slight downward trend in minimum discharge since 1948, potentially as a result of earlier snowmelt in the watershed. This trend is statistically significant at the 95% confidence level. This suggests that as climate warms, minimum flows of the McKenzie River at Clear Lake will decrease.

Modeling

The stepwise model for August discharge used four variables to explain 91% of the variation in the fitted dataset: precipitation accumulated at Santiam Junction by April 1st (P_{SJ41}, mm), the previous year's minimum discharge (Q_{min-1}, m^3/s), the previous year's winter temperature, and the April 1 SWE at Hogg Pass. The first two variables explain 84% of the variation in the fitted dataset and yield a regression equation of: $Q_{Aug} = 0.00573*P_{SJ41} + 0.45384*Q_{min-1} - 3.00216$. This model had an R^2 of 0.60 in the validation dataset, and underpredicts discharge in the validation dataset by an average of 0.6 m^3/s. When the fitted and validation datasets are combined, the overall R^2 is 0.78. The model predicts an average August discharge of 9.2 m^3/s for 2006, >60% of years in the 62 year period of record at Clear Lake.

Correlations with Major Climate Indices

Correlations between the monthly Niño 3.4 index for 1977-2004 and Clear Lake discharge annual discharge were highest for March ENSO with a correlation coefficient of -0.55 (significant at the 0.95 level). Correlation between mean August discharge and the Niño 3.4 index December of the previous year were weakly significant with a correlation coefficient of -0.35. Correlations between Niño 3.4 and SWE had much higher negative correlations. Santiam Junction peak SWE vs. Nino 3.4 from December of the previous year had a correlation of -0.60 (Figure 4). Hogg Pass peak SWE vs. Niño 3.4 from December of the previous year had a correlation of -0.54. Jumpoff Joe peak SWE vs. Niño 3.4 from December of the previous year had a correlation of -0.63. This indicates that ENSO, as explained by the Niño 3.4 index, is a reasonably good predictor of peak SWE and a moderate predictor of annual discharge.

We also explored correlations using the SOI but found that the correlations were much lower than for the Niño 3.4 index. Using the PDO index, we found that there were no significant correlations with annual discharge, August discharge or station SWE.

These results are similar to those of Beebee and Manga (2004) who found correlations between annual discharge, peak runoff and ENSO for eight snowmelt dominated watersheds in Oregon. However, they used the SOI averaged over June-September and Niño 3.4 averaged over September-November. We found lower correlations for seasonally averaged values of both SOI and Niño 3.4. Like Beebee and Manga, we also found no significant correlation with PDO.

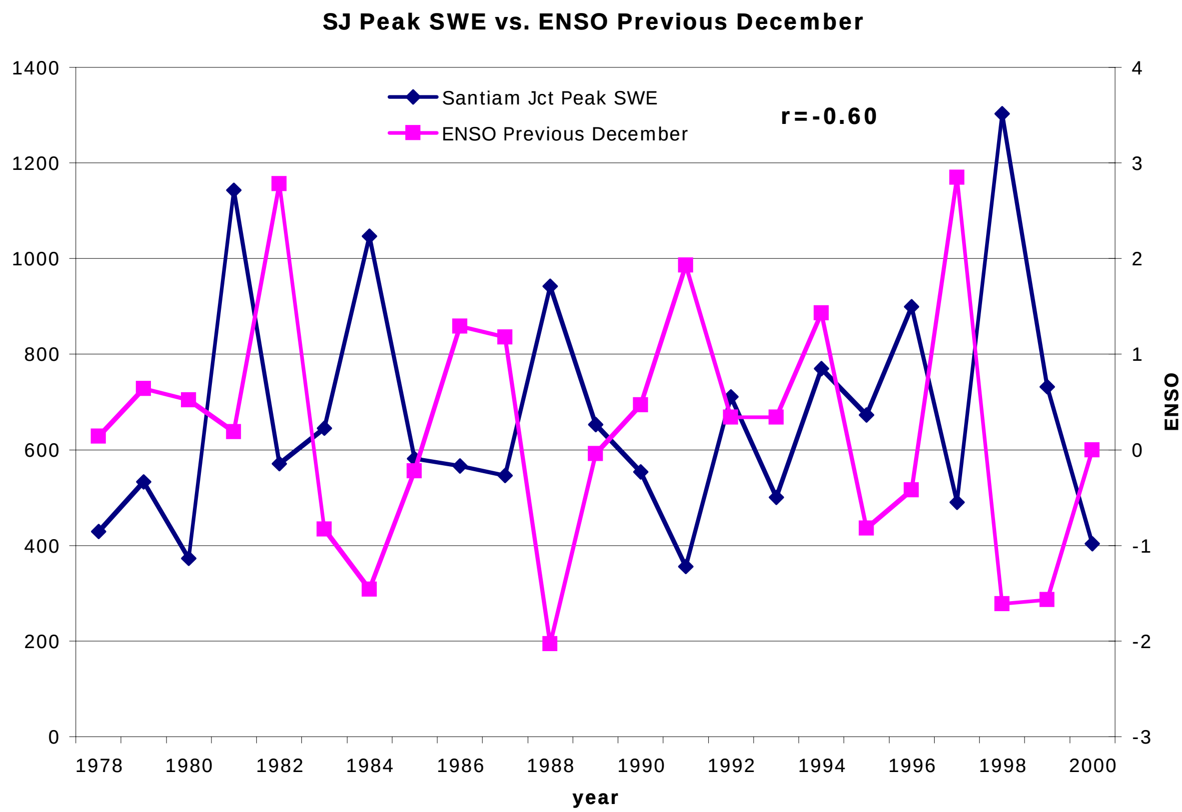

Figure 4. Santiam Junction peak SWE vs previous December Niño 3.4.

Discussion/Conclusions

The extremely permeable nature of the young basalts in the High Cascades leads to extensive groundwater systems, which make High Cascades watersheds, such as that of the McKenzie River at Clear Lake, the dominant sources of summer streamflow in western Oregon (Tague and Grant, 2004). Analyses of the historical datasets clearly highlight the importance of the groundwater system in sustaining summer streamflow. Groundwater storage and the associated slow recession are responsible for sustaining discharge even when the seasonal water balance is negative. Groundwater also helps buffer discharge from year-to-year fluctuations in precipitation, although it cannot fully mitigate a protracted multi-year drought.

The historical record suggests that minimum flows are declining as snowmelt occurs earlier. Earlier snowmelt causes the hydrograph to peak sooner in the spring, meaning that the recession from that peak to the beginning of fall rains occurs for a longer period of time and reaches a lower ultimate discharge. This has direct implications for stream temperatures, which are partly controlled by discharge, and are crucially important for threatened bull-trout that make the upper McKenzie River watershed their home. It is also important for water resources managers concerned with downstream water allocations and for the Eugene Water and Electric Board (EWEB) which generates electricity from a series of reservoirs downstream from Clear Lake. Lower streamflows will restrict junior water rights users and reduce the amount of electricity that EWEB can supply to Eugene.

Fortunately, along with the bad news about declining minimum flows, we report improved predictability of August streamflows. Using the regression equation provided above, water resources managers can predict average August flow as early as April 1. Peak SWE can be predicted as early as the previous December using an ENSO index. This allows time to assess consequences of high or low flows and plan mitigation strategies if necessary.

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Groundwater and Surface Water Resources in the

Basic Information

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Focus Category:	Education, Groundwater, None
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Principal Investigators:	Charles Rogers

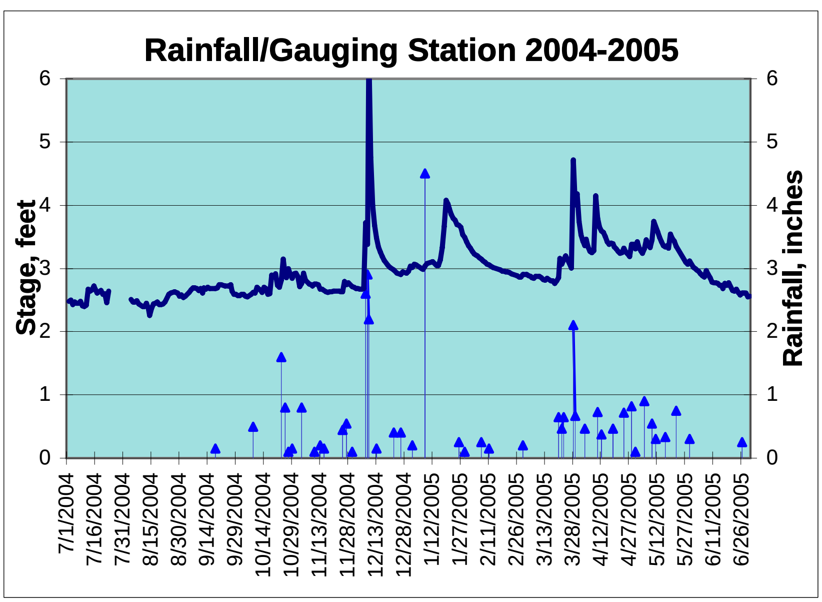
Publication

Groundwater Studies within the Williams Creek Watershed
by Charles Rogers

The recently completed *Williams Creek Watershed Groundwater Assessment* encompasses the need to understand the connection of groundwater to surface water and develop an understanding of the local hydrologic cycle and to use this knowledge in formulating policy and procedures in future management. Irrigation withdrawals and domestic well development in the Williams Valley affects streamflow along with the instream needs of aquatic wildlife. The information is vital in developing strategies that improve watershed health, provide for minimum instream flow, supply irrigation needs, consider domestic water needs, and in seeking methods to improve groundwater availability.

The purpose of this groundwater study is to collect information about the groundwater in the Williams Creek Watershed and investigate the potential for increasing efficiency of irrigation through the wise use of groundwater. Use of groundwater could alleviate some of the problems of withdrawal of surface water, but its overuse could also deplete the resources so other problems would be encountered. Our goals are to develop an understanding of the groundwater to promote wise and judicial use over time in order to maintain the resources without overuse and depletion. Overuse could result in output reduction in private wells and having to seek other sources for domestic use. Our objectives are to develop a plan to utilize groundwater resources without adversely affecting the amounts of water in the stream system for maintaining salmon and other aquatic species habitat.

The main conclusion drawn from this study is that groundwater is the main source of water for streamflow, especially during long summer dry spells. Winter rains produce high flows in streams but a steady base flow results from the discharge of groundwater. Steep terrain and rapid surface water outflow produces flashy surface systems as evidenced by detailed data collection by our new gauging station on lower Williams Creek. Groundwater originates from precipitation in the upland recharge regions, which are highly forested, and moves downslope to the lower topographic areas where most people live and wells are developed. This groundwater supply is highly dependent on annual precipitation.

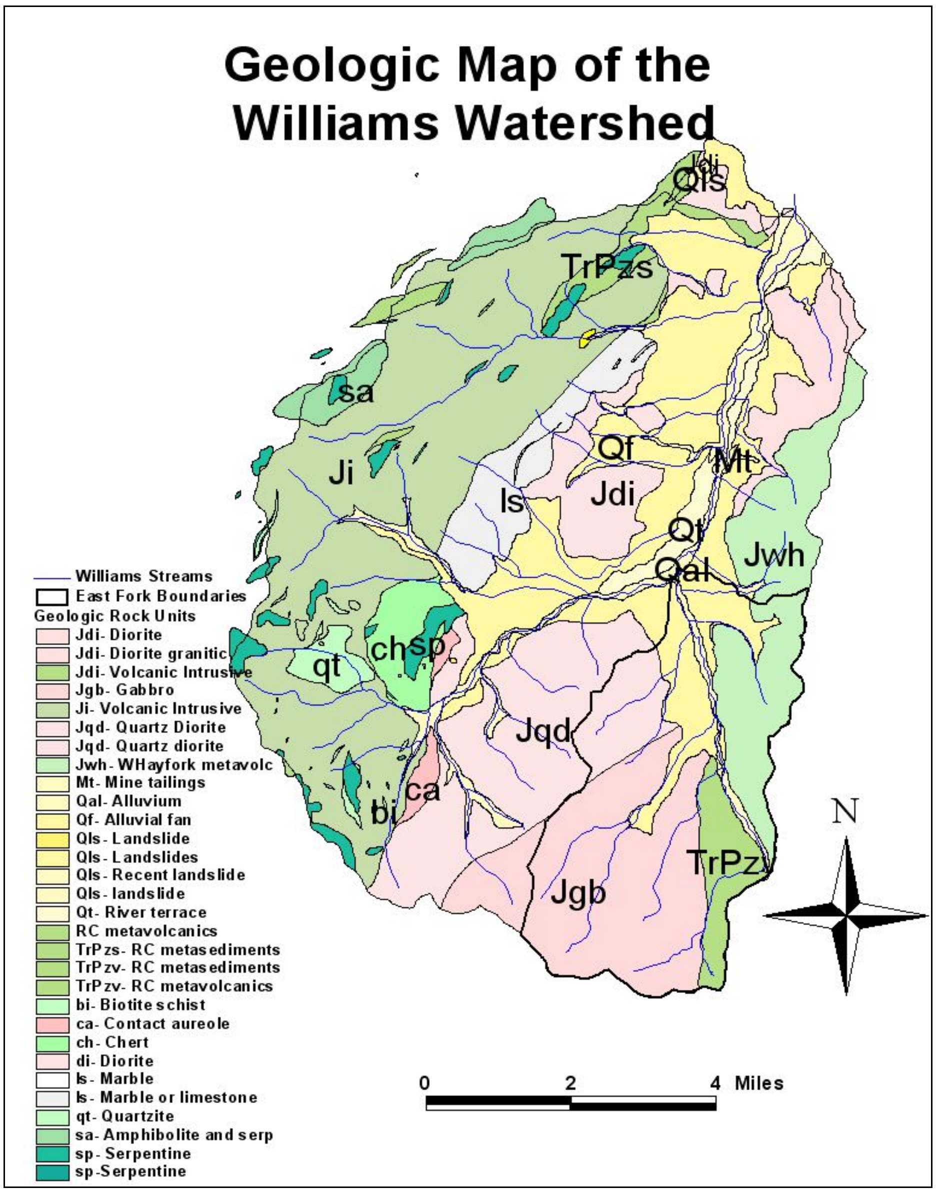


Williams Creek Gauging Station Recordings for 2004-2005

This graph shows the stage or height of the creek as a solid line with corresponding rainfall amounts shown as arrows rising from the bottom (collected in the upper watershed of the East Fork).

The general geology was mapped by Oregon state registered geologist, Robert Murray in 2002 and compiled for this study and reflects the latest known information available in this area.

The geology of the Williams Creek Watershed is composed of Klamath Mountain accreted terranes made up of volcanically derived sediments, volcanic island arcs, and granitic plutonic rocks. The eastern part of the watershed is composed of metavolcanic sediments and quartzites of the Applegate Group. Plutonic rocks of gabbro, quartz diorite, and diorite form a central north-south trending zone of multi-phase granitics that include the highlands of Grayback Mountain as well as the deeply eroded central part of the valley floor. The western ridges are composed of basalt, ultramafics, volcanic sediments, and marble lenses that are a part of mélange of accreted volcanic archipelagos of the Pacific tectonic plate. These terranes are separated by old subduction faults containing mylonites and other metamorphic rocks.



Our assessment considering the geology and well yields within the Williams Creek watershed is as follows:

1) Alluvium is the major aquifer in the Williams Creek Watershed. Where 10 feet or more of alluvium occurs below the water table, most wells obtain their water from the alluvial deposits. Well yields vary considerably and range from less than 10 gpm to 30 gpm or more in some areas with some wells reporting yields of 60 gpm or more.

2) Alluvial fans, like that found in the Powell Creek drainage produce large yields. Buried conglomerate, gravel, and other rocks produce good hydraulic conductivity. Other areas with landslide deposits that drain mountainous areas report large yields in wells.

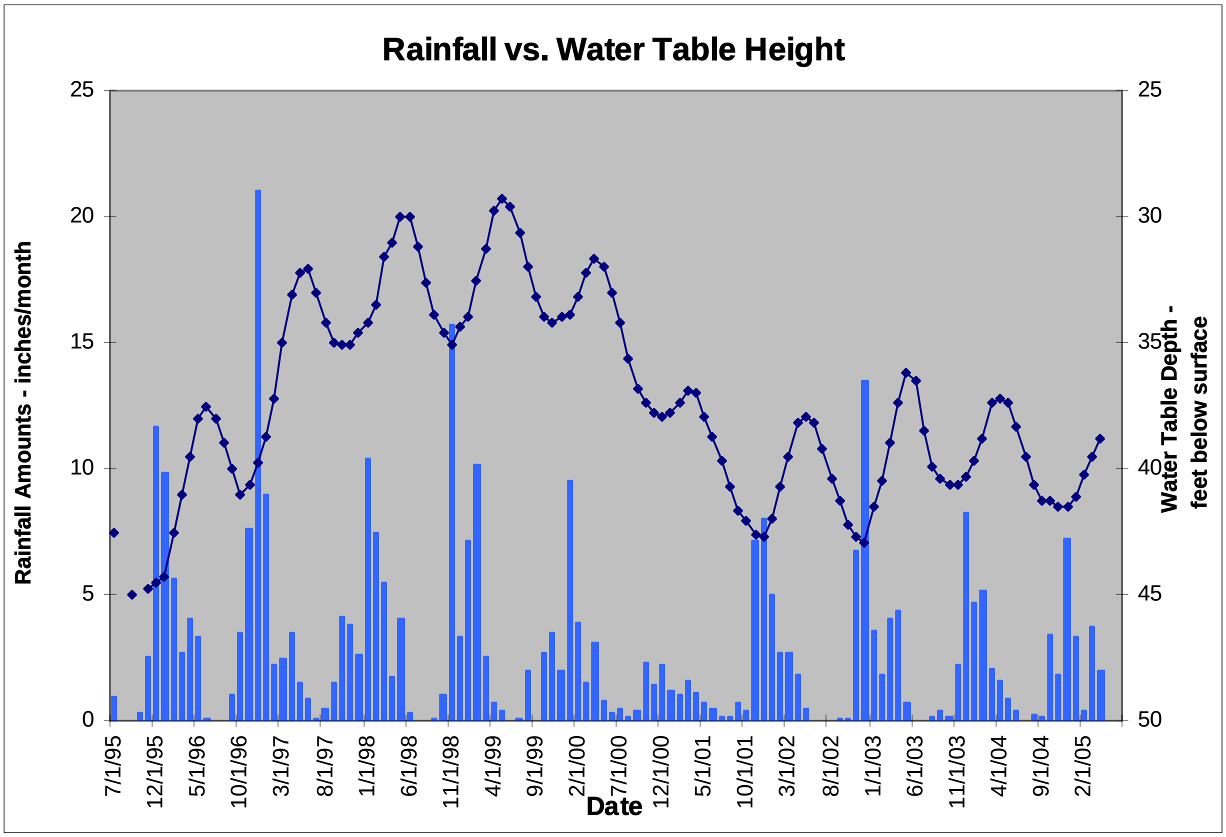
3) Granitic intrusive rocks of the Grayback Mountain Pluton serve as aquifers in areas where these rocks are found. Well yields depend largely on the depth and degree of weathering and the extent of fracturing of the rocks, which varies considerably throughout the watershed. Well yields range from 3 gpm in solid bedrock to areas with 60 gpm or more where weathered or fractured zones are encountered during drilling.

4) Well yields are generally small in the ultramafic and mafic rocks of the western ridges of the Williams Creek Watershed. The western ridge contains rocks of the Rattlesnake Creek Terrane composed of a mélange of volcanic, ultramafic, mafic, serpentine, quartzite, and marble. Few wells are drilled in this area but those reported show less than 10 gpm. Water quality is generally lower in these areas with one well showing presence of dissolved metals in water analysis.

5) The granitic alluvium shows the highest yields and contains the bulk of water resources in the Williams Valley. The depth to the bedrock is important in completion of wells as most water is encountered at the alluvial bedrock interface where groundwater is perched above granitic bedrock. Weathered granitic rocks can hold and transfer large amounts of groundwater and are found at the upper levels of the granitic basement below alluvial deposits. Fractured granitic rock is a good carrier of groundwater and is reported in the upper levels of the granitic bedrock. It is unknown where or how deeply fractured granitic rock occurs but wells drilled into these rocks can produce water yields in the 30 to 60+ gpm range. Water quality in these areas is good.

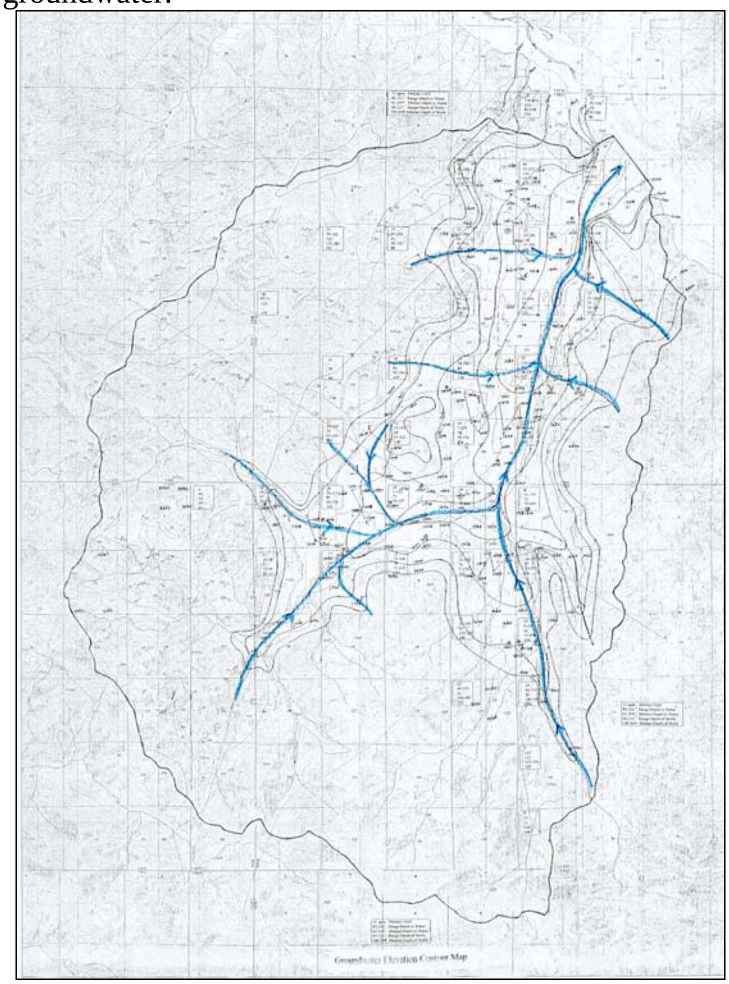
6) The eastern ridge of the Williams Creek Watershed contains metavolcanic rocks of the Applegate Group. Well yields in these areas vary considerably but yields are low unless fractured or concentrated by topographic features but are generally high enough for domestic use. Depths to water and total depth of well required may be greater in the steeper areas. Water quality is good but variable.

Groundwater movement is slow and lags behind general rainfall patterns. These lags produce higher water tables during early summer months and lower water tables during fall months with the lowest water table measurements occurring in December. The lag is highly variable from well to well, but is as much as 3 to 4 months in some areas. Groundwater fluctuations in monitored wells indicate that some wells have small vertical change in the water table over time while others have larger fluctuations. Groundwater levels fluctuate seasonally between 5 to 20 feet as measured in six wells. Any well use draws water from the groundwater supply and reduces the discharge into streams. If annual precipitation produces sufficient water for recharge, there will be little effect seen. If drought occurs, problems could arise in wells and irrigation systems throughout the valley, especially in the late summer months. Some wells will be fine for one or more years of drought. Others, particularly ones with low yields, will be the ones that will feel the drought effects.



The presence and distribution of groundwater in the watershed is perhaps the most important aspect in making the Williams Valley a livable and productive environment. If we had to select a geologic aspect that shapes and controls the lives of residents and wildlife alike, it would be the movement of groundwater. Groundwater movement is controlled predominately by the nature of rocks that underlie the surface, the topography of the basin, and geologic controls and boundary conditions. Groundwater generally moves slowly down gradient under the influence of gravity through rock and soils at differing rates depending on the physical characteristics of the unconsolidated and consolidated earth materials.

Higher elevation regions around the basin are the forested lands that constitute a major recharge zone of the Williams Creek Watershed. Infiltration rates vary considerably on differing topsoil and subsoil types, but vegetated soils and forested areas retain water onsite longer. Soil and vegetation slows runoff, which, if the permeability is present, will assist in infiltration of rain and snowmelt. Recharge zones are important components of groundwater systems because they are the major source of groundwater.



Surface water systems observable by numerous springs, ponds that are spring or groundwater fed, and perennial streams throughout the basin are dependant on groundwater to supply them with year-round water, especially during the summer months. Groundwater discharge is the major source for surface flow systems in this area.

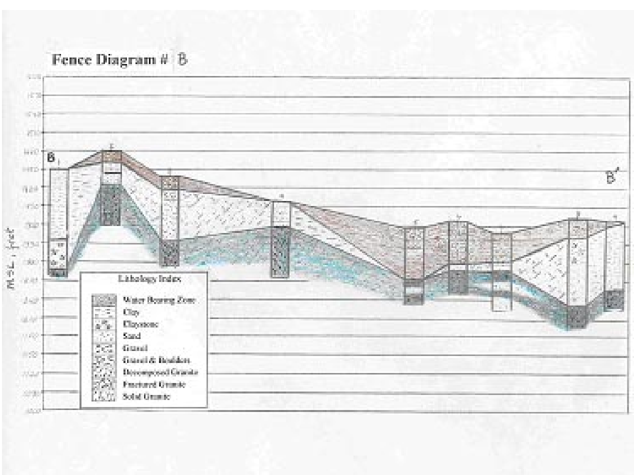
Alluvial Cross Sections and Fence Diagrams

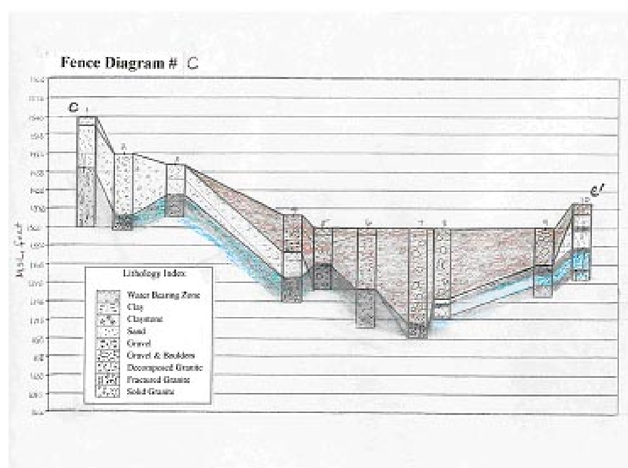
Fence diagrams are constructed from existing well log data and use the drillers report to analyze and develop an understanding of the water levels encountered along with the subsurface geology. Each log was studied for specific layers of rock that carry or resist groundwater storage and movement. Particularly important are the alluvial deposits that most wells are drilled into, including unconsolidated sands and gravels, weathered bedrock, fractured and solid bedrock.

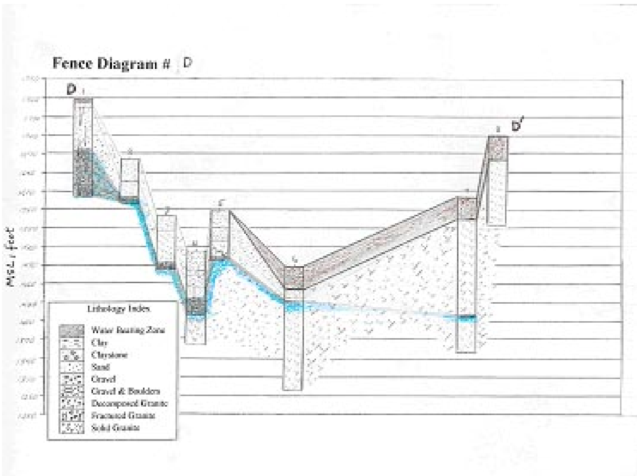
These fence diagrams show shaded areas that represent the alluvium at the top including soil, clay, sand, and boulders. They correspond to the cross sections on the well summary maps at the back of this report. The lower shaded area represents the reporting of water encountered at each well, connected by fence diagrams. The middle clearer area represents the granitic basement. Fence diagrams were located where wells were abundant, data was relatively reliable, and questions about groundwater are important.

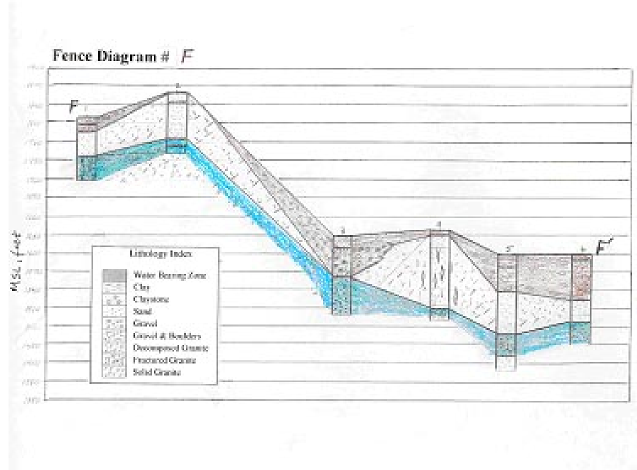
Fence diagrams have been simplified to show characteristics that are important to this study and can only be used as a guide to understanding the subsurface. The lithology Index included with the cross sections can be used as a guide to the rock type reported by drillers in well logs. Fence diagrams use the well logs as a guide to tie the regions between the wells to help understand the general patterns of subsurface deposits and their connection to groundwater occurrence.

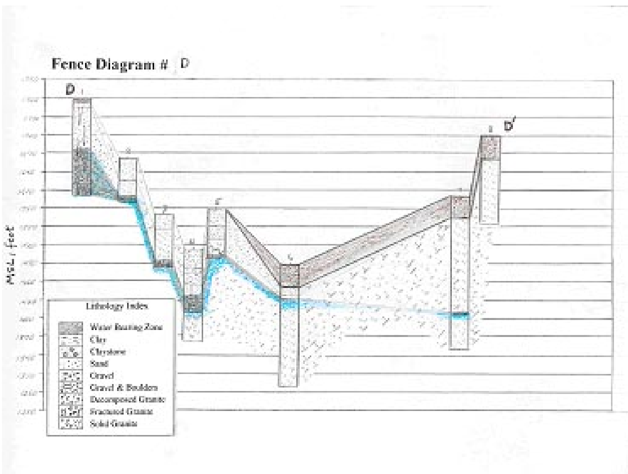
Well logs were interpreted by students at Southern Oregon University under a minigrant provided by the CWESt and the USGS. These diagrams have a vertical exaggeration of approximately 5 times the horizontal.











The final *Williams Creek Watershed Groundwater Assessment* is a 100-page report that contains all the findings and data collected. This study was funded in large part by the Oregon Watershed Enhancement Board, dedicated to improving watershed health and function with the goal of improving salmon habitat through good science and dedication of local communities. Supplemental funding was provided by:

- The Conservation and Research Foundation
- Mountaineers Foundation
- United States Geological Survey (USGS) and the Center for Water and Environmental Sustainability (CWest) from Oregon State University

Technical support was obtained from Ivan Gall, hydrogeologist for the Oregon Water Resources Department, Tom Wiley, state geologist of the Oregon Department of Geology and Mineral Industries, and geologic mapping by Robert Murray, Oregon State Registered Geologist. Local landowner, Lee Miles provided detailed science and data collection. Many other landowners provided access to monitor their wells. Finally, the Williams Creek Watershed Council Board helped establish and build the gauging station on Williams Creek. Thanks to all who helped make this report possible.

Development of a web-based database of hydrologic data for the Upper Oak Creek Watershed

Basic Information

Title:	Development of a web-based database of hydrologic data for the Upper Oak Creek Watershed
Project Number:	2005OR73B
Start Date:	7/1/2005
End Date:	6/30/2006
Funding Source:	104B
Congressional District:	Oregon
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Education, None
Descriptors:	
Principal Investigators:	Arne Edward Skaugset III, Arne Edward Skaugset III

Publication

1. Title:
   Development of a web-based database of hydrologic data for the Upper Oak Creek Watershed

2. Principal Investigators and Organizations:
   Dr. Arne Skaugset, Associate Professor, Department of Forest Engineering, College of Forestry, Oregon State University, Corvallis, Oregon.

3. Study Duration:
   Initiation Date: July 1, 2005
   Scheduled Completion Date: June 30, 2006

4. Research Objectives:
   The objectives of the project include:

   1) To create an internet-available database to provide non-proprietary data collected in the Upper Oak Creek Watershed in the MacDonald-Dunn Forest since 2001. Data include water discharge, precipitation, and weather data;
   2) Make available on the database, proprietary data collected from the Upper Oak Creek Watershed as it becomes published. Data will include discharge data from culverts and sediment yields from culverts and watershed boundary.

   This project is being carried out in the Upper Oak Creek Watershed of the McDonald-Dunn Research Forest of the College of Forestry at Oregon State University. A historic stream gauging structure is installed at the boundary of the school forest and all of the research takes place upstream of that structure. The area of the Oak Creek Watershed upstream of the gauging structure is 8.24 km^2. There are 4.57 km of road in the Oak Creek Watershed and there are 98 culverts installed on that length of road. Discharge is measured at the stream gauging structure at Oak Creek at the forest boundary and all culverts in the watershed. A meteorological station measures wind speed, solar radiation, air temperature, and relative humidity in the watershed. There are four tipping bucket rain gauges to measure rainfall intensity throughout the watershed.

5. Research accomplishments from this study:

   A database for the hydrology of the Upper Oak Creek Watershed was created and consists of the following data:
   1) Precipitation data summarized into hourly measurements from 2002-2005 for four rain gauges located spatially throughout the MacDonald-Dunn portion of the watershed.
   2) Climatology data from 2003-2005 including air temperature, wind speed and direction, photosynthetically-active radiation (PAR), and relative humidity measurements at 10-minute intervals.

3) Water discharge measurements from the Oak Creek gauging station at the forest boundary from 2001-2005 at 10-minute intervals.
4) Metadata characterizing the site location, data collection methods, and data processing tools.
5) As proprietary data from the watershed is published, it will be added to the database overtime. Data sets will likely include sediment yield from road segments and the forest boundary and discharge (runoff) from individual road culverts.

The database will be housed on the data website (http://www.fsl.orst.edu/lter/data/abstract.cfm?dbcode=HF022&topnav=97) of the H.J. Andrews Experimental Forest Long Term Ecological Research with other hydrologic data. The study code for the database is HF022. It will be available on-line after approximately July 15, 2006. To reach the broadest audience, the database will be linked from the Oregon State University Forest Engineering webpage (http://www.cof.orst.edu/cof/fe/researchgroups.php) and the Oak Creek Website (http://water.oregonstate.edu/oakcreek/index.htm).

6. Non-technical summary of the potential impact of this research

The primary benefit from this study will be to support teaching and research in the Oak Creek Watershed by making available commonly used and requested data.

Grant No. 03HQGR0118 Navigation Economic Technologies Research Program

Basic Information

Title:	Grant No. 03HQGR0118 Navigation Economic Technologies Research Program
Project Number:	2005OR78S
Start Date:	2/21/2003
End Date:	9/15/2005
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Congressional District:	
Research Category:	Social Sciences
Focus Category:	Economics, Management and Planning, Models
Descriptors:	navigation, economics, technology
Principal Investigators:	Wesley Wilson

Publication

The Navigation Economic Technologies Program

January 25, 2005

NETS

navigation · economics · technologies

A MODEL OF SPATIAL MARKET AREAS AND TRANSPORTATION DEMAND

US Army Corps of Engineers®

IWR Report 05-NETS-P-01

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

For further information on the NETS research program, please contact:

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U.S. Department of the Army
Corps of Engineers
Institute for Water Resources
Casey Building, 7701 Telegraph Road
Alexandria, VA 22315-3868

The NETS program was overseen by Mr. Robert Pietrowsky, Director of the Institute for Water Resources.

January 25, 2005

NETS

navigation · economics · technologies

A MODEL OF SPATIAL MARKET AREAS AND TRANSPORTATION DEMAND

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For the:

Institute for Water Resources
U.S. Army Corps of Engineers
Alexandria, Virginia

IWR Report 05-NETS-P-01

www.corpsnets.us

TITLE: A MODEL OF SPATIAL MARKET AREAS AND TRANSPORTATION DEMAND

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WORD COUNT: 5781 + 1500 (3 tables and 3 figures) = 7281

ABSTRACT: In this paper, we derive a model of transportation demand and the interrelated supply decisions of agricultural shippers over a geographic space. These shippers use prices to both procure grain and to make output, mode, and market decisions. These decisions are each affected by the characteristics of the region and the level of spatial competition between the shipper and its rivals. We integrate each of these factors into our model of derived demand and spatial competition. The model is applied to data representing barge elevators on the Upper Mississippi and Illinois Rivers to estimate transportation demands and gathering areas. The results provide demand elasticity estimates for annual volumes between -1.3 to –1.9, estimates which are sizably larger than previous estimates of similar traffic. The results also indicate that inbound transportation rates to the barge shipper has a significant influence on annual volumes as does the distance to the nearest competitor. A second model, explaining the size of the market area of elevators is also estimated. We find that the rates of alternative modes that compete for barge traffic have a strong influence on market areas as does the distance to the nearest competitor. The results provide for a strong argument that transportation demands are elastic and that spatial market areas vary substantially with transportation rates.

1. INTRODUCTION

Current navigation planning models define demands in terms of originating and terminating pools for a specific commodity on an annual basis (ODC). These models differ with regard to assumptions on the behavior of demand in response to rate movements. The Tow Cost (TCM) and ORNIM models hold that demands are constant up to a threshold level (e.g., the least cost rail rate) at which point all traffic flows to the alternative mode. The ESSENCE model holds that these demands are not constant, but rather fall as price increases until that same threshold point is reached. The basis for this treatment is that demanders are distributed geographically over space and that as price increases, shippers that define the ODC triplicate demand less barge.

These OCD triples reflect the decisions of port elevators. Our approach is to examine the responsiveness of these elevators to barge rates. Specifically, barge rates are a determinant of the price that elevators offer to shippers located off of the river. As barge prices increase, the price increase is passed on to those shippers that use the elevator. To the extent that these shippers have alternatives or respond to price decreases, the river elevator ships less down the river.

We model these decisions using a spatial modeling approach. For the past century economists have been interested in the effects of space on economic competition. Clark and Clark (1912) were the first to examine how firms competed over customers in a spatial context. Many theories have followed most notably Hötelling (1929) and Lösch (1941). All of these theories, while theoretical in nature, agree that as transportation costs increase the size of the firm's market area decreases and that as the distance between firms increases the size of the firm's market area increases.

While numerous theories exist to explain how firms interact over space, very little work has been done on empirically estimating these relationships. This lack of research has stemmed from the lack of real world data available on firms in a spatial context. We add to this literature by theoretically and empirically analyzing the quantity shipped and market areas of agricultural elevators located along the Mississippi and Illinois Rivers taking into account the spatial relationships and characteristics of the elevators. We find that, controlling for location, the firm's market area decreases in size as the distance between the origin location and destination location decreases. We additionally find that demand elasticity estimates for annual volumes of between -1.3 to –1.9, estimates that are sizably larger than previous estimates of similar traffic.

In Section 2, we provide a more complete summary of the literature on firms in a spatial context paying particular attention to pricing over geographically dispersed customers. In Section 3, we present a theoretical model of spatial competition and market areas for agricultural elevators. Section 4, details the empirical model used to estimate the firm's market areas in a spatial context, while Section 5 outlines the data used for the analysis. Section 6 presents the results of this estimation technique, while in Section 7 provides concluding comments.

2. PREVIOUS LITERATURE

The spatial economics literature consists of two interconnected areas of focus: market areas and spatial pricing/competition. These areas aim to describe how a firm's set of customers changes as the firm changes its pricing policies, given the spatial distribution of customers. Related research examines the spatial location of firms given optimal pricing. Previous literature tends to address each of these issues individually rather than combining them. Following this tradition, we take locations as given and model the pricing behavior in conjunction with spatial characteristics to explain the prices paid to farmers, the volumes shipped by the elevator and, consequently the volume shipped via the river.

Clark and Clark (1912) is the first attempt to explain how firms located at different geographic points compete for customers. In this study, each firm's market share is determined by the location of the customer indifferent between the firm and its nearest competitor. This indifferent point is based on each firm's base price and the transportation costs of the customer to each location. Fetter (1924) follows the work of Clark and Clark (1912) by examining the shape of each firm's market area. Fetter (1924) surmises that it is unlikely that there is only one indifferent customer located between the firms, but rather there must be a band or series of such customers located at varying distances between the two firms. This series of customers thus constitutes the shape and extent of the firm's market area.

According to Fetter's "Law of Market Areas" the difference between each firm's base price and that of its nearest competitor determine both the size and the shape the firm's market area. An increase in freight rates acts to move the indifferent customer further away from the higher priced firm, increasing the market area of the lower priced firm. Alternatively, it will allow the lower priced firm to raise their prices while retaining the same market area. If the firms have identical base prices such an increase in the freight rates will not change the indifferent customer only the price that they face.

The most notable work done on spatial competition is Hötelling (1929). This work mathematically formalizes the models of both Clark and Clark (1912) and Fetter (1924). Hötelling (1929) assumes that buyers are distributed evenly on a line, that each buyer faces constant transportation costs, and that demand is inelastic. These buyers then must decide which firm of two firms to purchase from. Unlike previous work, Hötelling (1929) then allows firms to respond to their competitors through either price or location decisions. Using this approach, each competitor is found to adjust their prices, taking their competitor's price as given, to maximize profits. Proceeding in this fashion, each firm finds it profitable to locate closer to their competitor because they can attract more of the customers located between the two firms.

Much later, D'Aspremont, Gabszewicz and Thisse (1979) prove that the Hötelling (1929) model does not prove that firms will cluster in the middle of the market. With homogeneous products, as two firms move closer together they have to charge a price equal to that of their competitor plus transportation costs. Such a pricing system would drive price, and subsequently profit down as the firms move closer together because of the increased competition from their rivals. Indeed D'Aspremont, Gabszewicz and Thisse (1979) argue that duopolists should like to locate apart and divide the market, allowing each firm to gain some degree of market power.

Another line of work regarding firms in space focuses on the shape of firms' market areas. The most notable work in this area is Lösch (1954) who argues for the existence of hexagon shaped market areas so that the market is "full". Mills and Lav (1964) later show that under the assumption of linear demand both profits and market areas are maximized with circular market areas. They also examine other shapes and conclude that dodecagon shaped market areas are equilibrium market area shapes.

Later research, e.g., Eaton and Lipsey (1976) find that many market shapes satisfy the equilibrium conditions of their model including squares, rectangles, and hexagons. In fact, the only market shape that they could conclude would not satisfy their equilibrium conditions was an equilateral triangle market area. The reason that Eaton and Lipsey's (1976) result varies from that of Lösch (1954) is because they assume that all firms charge the same exogenously imposed mill price. Our model differs from much of this primary research by taking the location of the firms as fixed and focusing on effect of the spatial distribution of firms on pricing and the gathering area for port facilities. In particular, we consider the effects of pricing and the spatial distribution of firms (and other variables) on output and the size of the market area. Of course, the concepts of Clark and Clark (1912), Fetter (1924) and others are retained in the sense that the firms base price and the set of indifferent customers determines the geographic space titled "market area". We note that in our data, elevators tend to agglomerate in some areas and separate in others, leading to elevator competition between areas and within areas.

3. THEORETICAL MODEL

Our primary focus in this paper is the movement of agricultural products. Production of agricultural commodities occurs over space, and transportation of such commodities is a critical component of agricultural markets. At harvest, goods are transported from the farm to a storage facility, a gathering point, or to a final destination. The gathering points are transshipment points, represented by country elevators, rail sub-terminals, and/or barge loading facilities. From these points, there is further transportation to the final destination. By and large, commodities almost always pass through one or more of these gathering points for transshipment to another location. Ultimately, the commodities reach their final destination. The final destinations are numerous. Such final destinations include processing plants, feedlots, and export markets.[1] Our data, described in a later section, represent the transportation decisions of what we term transshipment locations. That is, they receive commodities from the farm or another gathering point, and ship to another location in the transportation infrastructure.

The model we develop in this section is a model of grain elevator competition that gives rise to a procurement function defining the relationship between an elevator's market area and characteristics of the firm, its rivals and the space that they are competing in. Since we are specifically looking at grain terminals located along both the Mississippi and Illinois rivers, we model elevators located in a linear geographic space. For simplicity and clarity, we assume that there are $n=1,2,....,N$ elevators located $D=d_{12},d_{23},....,d_{n-1n}$ miles apart from one another, and that grain per mile is evenly distributed between the elevators with parameter y.

We assume that farmers sell their grain to the elevator that yields them highest returns net of transportation costs $(w^e + \delta_e - \theta D^e)$ where w^e is elevator e's bid price, δ_e is the farmer's preferences for elevator e, θ

[1] Our focus is on US shipments. As such, we include export market as a "final" destination. Of course, once at the export elevator, there is another set of transportation and marketing decisions from which we abstract.

is the farmer's cost per unit distance, and D^e is the distance from the farmer's location to elevator *e*.[2] The farmer's problem then is treated quite simply. That is, once the decision to sell has been made, our model is simply a decision of where to sell to from a set of locations. We translate grain locations into distances, and assume that no one elevator offers a price high enough to price the other elevators out of the market.

Consider farmers producing grain. Further, suppose that these farmers are located between two elevators (A and B). The indifferent farmer is located such that

$$D^A = \frac{w^A - w^B}{2\theta} + \frac{\delta_A - \delta_B}{2\theta} + \frac{D}{2} \tag{1}$$

Note that the distance the indifferent farmer is from elevator A, D^A, is increasing in the price A offers, $\frac{\partial D^A}{\partial w^A} > 0$, decreasing in the price B offers, $\frac{\partial D^A}{\partial w^B} < 0$, increasing in farmer tastes for elevator A, $\frac{\partial D^A}{\partial \delta_A}$, decreasing in farmer tastes for elevator B, $\frac{\partial D^A}{\partial \delta_B}$, increasing in the distance between the two elevators, $\frac{\partial D^A}{\partial D} > 0$ and ambiguous in the farmer's transportation cost, θ.

For an elevator (A) that serves farmers located between elevators A and B and elevators A and C, total output is given by the total produced (*yD*), and its share of the distance between A and B and A and C, which we denote D^{A-B} and D^{A-C} as defined by (1). Total output for elevator A given prices is then:

$$\begin{aligned} Q^A &= Dy\left\{ \int_0^{D^{A-B}} \frac{1}{D} dt_1 + \int_0^{D^{A-C}} \frac{1}{D} dt_2 \right\} = Dy\left\{ \frac{D^{A-B}}{D} + \frac{D^{A-C}}{D} \right\} \\ &= \frac{y}{2\theta}\left\{ 2w^A - w^B - w^C + 2\delta_A - \delta_B - \delta_C \right\} + \frac{Dy}{2} \end{aligned} \tag{2}$$

Elevator A's output is increasing in the price it offers, but decreasing in the price of its rivals. Note that if prices and non-price characteristics are the same, the elevators simply split the market area. If prices are different, then there are a number of effects. First, greater distances between elevators increase total regional output and, hence, the quantity each elevator handles. Second, an increase in farmer transportation costs reduces the effectiveness of pricing differences on the market area, and therefore, the quantity of the higher priced elevator. Of course, since all goods are shipped, it has the effect of increasing the quantity of the lower priced elevator. Finally, as with increases in the distances between elevators, increases in the grain yield result in a larger total market with no change in market area resulting in an increase in production at each elevator. Third, and increase in farmer preferences for elevator A relative to elevators B and C, leads to an increase in elevator A's output.

We use this expression to define the output, i.e. market area, of a representative elevator that competes with others over geographic space. The expression given by (2) is a deterministic relationship in the model i.e.,

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[2] δ_e enters this equation to control for non-price differences across farmer's utility functions. For example, one farmer may like the options provided to it by using a large multi-plant companies elevators, while a different farmer may prefer his/her local cooperative elevator to the large corporative elevators.

there is a unique w^A for a corresponding output level (Q). However, for the purposes of this section, we invert the expression given by (2) such that Q can be the choice variable. The result is:[3]

$$w^A = \frac{1}{2}\left\{w^B + \delta_B + w^C + \delta_C\right\} + \frac{\theta}{y}\left\{Q^A - \frac{Dy}{2}\right\} - \delta_A \tag{3}$$

Given equation (3), the costs of procurement for the firm are simply:

$$C^{\text{Procurement}} = w^A Q^A = w^A(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C)Q^A = C^{\text{Procurement}}(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C)$$

with the properties that marginal costs are positive and increasing in Q.

In addition to procurement, there is the cost of the elevator company to operate over and above just the costs of procurement over a geographic space. On this matter, we simply assert that such costs are positively related to activity levels (Q), factor prices (w), and non-positively related to fixed asset levels (e.g., capacity, K). That is, $C^{Operations} = C^{Operations}(Q, w, K)$. With operations and procurement identified, the total cost function of the facility making transportation decisions, is given by:

$$\begin{aligned} C^{Elevator} &= C^{Operations}(Q^A, w, K) + C^{\text{Procurement}}(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \\ &= C(Q^A, w, K, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \end{aligned} \tag{4}$$

There are a few notes of interest in regard to this cost function. First, we constructed this model for the specific purpose of solving an optimization program of shippers that must procure their product over space. While most shippers face this type of problem (i. e., the gathering of inputs over space and the dissemination of outputs over space), it is not a common treatment. Specifically, we note that the cost function depends on the input prices of rivals (The price paid by neighboring elevators). The more common treatment is simply to ignore the spatial procurement of inputs and specify costs as one of operations in our discussion above. So long as this cost function has increasing marginal costs, the remainder of the theory present applies.

Second, a necessary condition for the procurement cost function to be increasing in output, is that the neighboring shippers do not respond to the price changes of the elevator or that the response is less than a direct matching of prices. If there is a direct matching of price changes, quantities will not change. This can be seen by totally differentiating equation (2) and imposing the restriction that price changes are equivalent. This issue is overcome in our model where we allow elevators to offer differentiated services. There are, however, lots of differences among elevators in terms of yields, capacity levels, transportation attributes etc., that allow for a non-trivial result.

The firm then chooses Q^A, which implicitly determines w^A given the bid prices, and preferences for its rivals. The elevator must additionally decide where to ship the commodity to and what mode to ship with, so as to maximize their profits defined as:

$$Max\, \pi_{md} = (P_d - t_{md} - s_{md})Q_{md} - C(Q_{md}) \tag{5}$$

where P_d is the price that the elevator gets for the commodity at its destination, t is the transportation costs associated with shipping the commodity to that location from the elevator via shipment mode m, and s is the service characteristics of shipment mode m from the elevator to the destination. Assuming that larger shipment sizes are harder to obtain (e.g., the shipper must increase its bid price to increase its gathering area or to induce farmers to reach a reservation price or, alternatively, processing gets more costly with larger sizes), the solution yields how much the shipper will send to the terminal location by a given mode.

[3] As intuition, note that if all firms priced the same, then $Q - Dy$ must take a value of zero. For this to happen, each firm serves one-half of the distance to each of its neighboring rivals.

Theoretically, this quantity is a function of the price at the destination, the transportation rate, service induced costs, and procurement/processing costs determinants.

$$Q_{md}^{*} = Q_{md}^{*}(P_d, t_{md}, s_{md}, c, D, y) \quad (6)$$

where c is simply the set of parameters of the cost function that we derived previously.

Given the first-order condition to equation, we can see how changes in each of the determinants of equation (6) affect the profit maximizing quantity, market area, for an elevator. An increase in P_d, the price that the elevator gets when it ships the commodity, will not surprisingly increase the quantity, or market area, of the firm. In addition, as the distance between elevators increase, so do the prices offered farmers with the result that both output and market areas increase. Increases in t_{md}, s_{mn}, or c will decrease the quantity, or market area, of the firm. Examining the elements of c, the cost parameter closer, we see that increases in factor prices and the bid prices of rivals increase costs, thus reducing both profits and the firm's quantity, or market area. Meanwhile, increases in capacity (K), grain per mile (y) and distance between elevators (D) reduce costs therefore, increasing both profits and the firm's quantity, or market area.

These changes, however, may induce another effect. In particular, as prices, capacity, yields, distances between elevators, etc. change so do the profits attached to the elevator's discrete decision of where to ship (i.e., the terminal market) and the how to ship (i.e., the mode).

4. EMPIRICAL MODEL

From the theoretical model, we derived an equation, (6), which defined the quantity shipped by an elevator as a function of the price that the elevator gets when it ships the commodity, transportation costs of shipping the commodity, the service characteristics of the mode, the costs of operation, farmer preferences for non-price characteristics of the elevators, crop production, and the distance to competitors. In this section, we present an empirical framework to examine these relationships.

As noted previously, we notice some elevators agglomerating together while other elevators separate out. Because of this fact, we assume that the agglomerated groups of elevators compete across groups for business, and that once the farmer has decided to bring their crops to one area over the other areas, the firms within an area compete amongst each other for that business. Thus, to equation (6) we add several measures of area characteristics including the number of firms in the area, the capacity of elevators in the area, and a dummy variable for firms located at the same location. Additionally, while we have modeled the competition between river terminals, we recognize that off-river terminals also compete for business with the river terminals. We do not observe the output of these locations; however, we do observe the alternative transportation rate for the river terminals which we put into equation (6) to control for the share of the market the river terminal gets when competing with the off-river terminal. Finally, we note that there are two basic types of firms: large conglomerate firms with many locations and independent or cooperative local firms. We add a dummy variable to equation (6) to control for each of these types of firms. Empirically, based on equation (6), and the aforementioned observations, the model we estimate is given by:

$$\begin{gathered}\text{Annual Tons} = f(\text{barge rate, alternative rate, transportation rate from farmer to elevator,}\\ \text{distance to nearest competitor, dummy variable for elevators located at the same location,}\\ \text{firm capacity, \# of firms in area, capacity of firms in area,}\\ \text{dummy variable for large conglomerate firms, area production})\end{gathered} \quad (7)$$

Where *barge rate* is the rate per ton-mile of the barge movement; *transportation rate from farmer to elevator* is the rate per ton-mile of trucking or rail to the rail loading facility (i.e., in the context of the model presented earlier, it is the farmer's transportation cost); *alternative rate* is the rate per ton-mile of the most common alternative to shipping down the river, an element of mode choice from our theoretical section; *distance to nearest competitor* is the distance to the nearest competitor; the *dummy variable for elevators located at the same location* is equal to one for firms located one mile or less from their nearest competitor and is designed to capture any agglomeration effects; *capacity* is the capacity in bushels of the firm; *number of firms in area* in the number of competing elevators in the same county and bordering counties; *capacity of firms in area* is the capacity of the firms in the same county and bordering counties; *area production* is the average production of the commodity in the county and bordering counties; and the *dummy variable for large conglomerate firms* is a dummy variable equal to 1 if the shipper is one of the six conglomerate firms in our sample.[4]

We expect the effect of the barge rate to be negative (the law of demand), the effect of the alternative rate should be positive because as the alternative rate increases, it should increase the river terminal's market area when competing with its off-river rival, and the transportation rate (θ in our theory) has a negative effect. We also expect the distance to competitor (D from our theory) to increase annual tonnages. Capacity should also increase production, the number of firms in the area has an ambiguous effect (it increases competition which should decrease quantity, but farmers from far distances are more likely to ship to an area where there are many choices and then choose which to use when they arrive), the capacity of the firms in the area has a negative effect because larger firms around you means stronger competition, and area production (y from our theory) has a positive effect.

We additionally estimate equation 7 with gathering area instead of annual ton-miles as the dependent variable. This is done to investigate how firm market areas change as each of the independent variables change. In particular, we investigate whether market areas indeed increase as the distance between competitors increases as previous theoretical work indicates.

5. DATA SOURCES AND VARIABLES

The majority of data used for this analysis came from the Tennessee Valley Authority (TVA). TVA collected these data during two sets of personal interviews of barge terminals located along America's inland waterways. For this study, we employ a subset of the data. In particular, we limit ourselves to the activities of the 103 grain elevators located on the Upper Mississippi and Illinois rivers.

As indicated Figure 1, the terminal locations of agricultural shippers are not uniformly distributed as many of the previous theories of spatial competition and market areas assume.[5] Instead, we observe clusters of observations and single observations at others. Since we are examining grain elevators, an obvious explanation for this clustering in some areas is the differences in crops across areas. As indicated in Figure 2, this is indeed the case. The darker areas represent increasing farm densities starting at 0 farms per square mile.[6] The majority of the elevator clusters fall within the areas of high farm density.

During the course of their interviews, the TVA collected information regarding each location's annual tons shipped, commodities shipped, barge charges, truck transfer charges, the termination of the shipments, their average gathering area of product to be shipped, and alternative routes that they could have sent that shipment if not by barge.

Figure 3 contains median gathering areas for some of the elevators. We calculated these gathering areas by grouping the elevators together according to their location along the river and then calculating the median gathering area of the elevators in each grouping. These median gathering areas were then graphed in the

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[4] We used several distances to classify firms as being in the "same location", the results were robust across specifications of this distance; however, the r-squared was maximized by using 1 mile which is why we chose to use 1 mile as our "same location" criteria.
[5] We matched the TVA data with the USACE Port Series to obtain these terminal locations.
[6] We use the Environmental Systems Research Institute's (ESRI's) Farm Density measure for this figure which was taken from the number of reported farms in 1997.

center of the geographic group. Not surprisingly, we observe the largest median gathering areas where the farm densities are the highest.

We supplemented these data with crop yields per acre and harvest levels at the county level from USDA. Summary statistics are provided in Table 1. These statistics suggest there is considerable variation in annual ton-miles shipped. That barge rates per ton-mile are, as expected, much smaller than alternatives (rail and truck). Rates inbound to the shipping elevator are approximately 7 time higher than the barge rates, but much less than the alternative rate, owing to shorter distances. Firm capacity and area capacity vary quite a bit from elevator to elevator. The distance between elevators is about 1.75-6.5 miles, while the number of firms in the same area appears to be approximately 4-5.25. There also appears to be considerable variation in the area production of crops. Finally, the gathering area (the distance of inbound shipments) has a centile value of 60 miles and an average value of about 68.3. Further, a simple regression of gather and river mile indicates that gathering areas increase with river mile, and a 100 mile increase in river mile increases gathering areas about 4 miles. From the lower reaches of the river to the most northern areas, this suggests a difference in gathering area of about 33 miles.

6. RESULTS

Because of the groupings of firms as indicated in Figure 1, we estimate four different models on equation (7). First, we estimate equation (7) using annual ton-miles as our dependent variable and then we estimate equation (7) using gathering area as our dependent variable. When estimating these equations, we use both OLS and a fixed effects model by area (as defined above).[7] We use the fixed effects model to control for any unobservable characteristics of either the waterway or land located around each elevator. For example, several elevators might locate close together just downstream of a lock which is consistently congested.

The results of the four regressions using annual ton-miles as the dependent variable are reported in Table 2. While the four regressions using gathering area as the dependent variable are reported in Table 3. In all models, we use log forms for the continuous variables.

The first two columns in Table 2 are the OLS estimates of annual ton-mile regressions, while the last two columns reflect the fixed effects estimates of annual ton-miles. The second and forth columns include all of our spatial measures (i.e. number of firms in the area, capacity of the firms in the area, distance to nearest competitor, the dummy for same location, and area production), while the first and third column exclude them. We present the regressions in this way to assess the stability of the coefficients of interest with respect to the spatial characteristics of the elevators.

The two OLS models fit the data with R-squares of 36 and 40 percent. In both columns one and two the coefficient on the barge rate per ton-mile is about -1.5 (this is an estimate of the elasticity of demand for barge shippers). Inbound rates should and do affect annual tonnages, showing that as inbound rates increase by one percent, there is a corresponding decrease in annual tonnages by about 1.2 percent. The effect of alternative modes of transportation is not statistically significant. This may be explained by the observed fact that, in our data, we do not observe shipments being shipped by methods other than barge from the river terminal locations.. The firm's capacity is not statistically significant in any of the models. The results also indicate that elevators who primarily ship corn as opposed to wheat or soybeans ship a larger quantity annually. In both OLS specifications conglomerate firms ship more than non-conglomerate firms. Area production is found to be positive and significant, indicating that elevators in areas where more crops are produced ship more quantity annually.

The results presented in columns 3 and 4 of Table 2 reflect the same effects on the annual ton-miles of the shipper using fixed effects to control for unobserved differences in the areas where the elevators are located. These two specifications fit the data with R-squares of about 52 and 60 percent, a marked improvement from the straight OLS models. However, the F-test for the use of such fixed effects is

[7] An early reader noted our lack of destination price, which we do not observe. However, we do observe destination, and when we include dummy variables for each location, not only do our results not change, but none of the dummy variables are statistically significant.

statistically insignificant with a p value of .12 when controlling for all other spatial characteristics in column 4. In column three the coefficient on the barge rate per ton-mile is -1.33 while in column 4 it is -1.90, both being statistically significant. Inbound rates are found to only affect annual tonnages in the fixed effects model controlling for the observable spatial characteristics of the elevator, showing that as inbound rates increase by one percent, there is a corresponding decrease in annual tonnages of 1.1 percent. The effect of alternative modes of transportation is not statistically significant. The firm's capacity has an insignificant effect on annual ton-miles shipped. The results again indicate that elevators who primarily ship corn as opposed to wheat or soybeans ship a larger quantity annually. In both specifications conglomerate firms ship more than non-conglomerate firms, but the effects are statistically significant only when we control for the observed spatial characteristics. Column 4 shows that when controlling for both the observable spatial characteristics and the non-observable spatial characteristics (through fixed effects by area) many of the observable spatial characteristics are significant. The distance to nearest competitor variable is both positive and significant indicating that firms ship more the farther they are from their nearest competitor. Area capacity is negative and significant indicating that if you are located near firms capable of shipping large quantities you ship less output. Additionally, the number of firms in the area is positive and significant which coincides with our previous story that farmers may ship to areas where there are many firms and then make there decision of who to sell to when they get to that area. All of these area characteristic variables indicate that there is competition going on both between areas and between firms within areas as we suggested previously. Finally, area production is positive, but insignificant when using fixed effects.

In Table 3, we present the results for these same four specifications using gathering area as our dependent variable rather than annual ton-miles. In the OLS models, alternative rate is negative and statistically significant, indicating that as the alternative rate increases, elevators' gathering areas shrink. One interpretation of this result is that as the alternative rate increases farmers find shipping to the river elevators more appealing and thus the river elevators can reach their profit maximizing quantity with a smaller gathering area. Across all four specifications presented in Table 3 we find that elevators who ship more corn than soybeans and wheat tend to have smaller gathering areas, and that conglomerate firms have larger gathering areas. Examining column four where we control for the spatial characteristics, both observed and unobserved, we see that elevators' gathering areas increase as the distance from their nearest competitor increases, and that firms located at the same location have larger gathering areas. Both of these results coincide with our predicted theoretical outcome. Additionally, we find that controlling for the unobserved fixed effects in this model is warranted with an F-test.

All four annual ton-mile specifications show that demand for barge movements is elastic with estimated elasticities between -1.33 and -1.90. We also demonstrated that the spatial characteristics of the elevators affect their quantity shipped and that these characteristics need to be controlled for when estimating such demand models. Additionally, all of our results are stable and robust across all estimation specifications.

7. CONCLUSIONS

This paper develops and estimates a model of spatial competition with a direct link to transportation demands. Transportation demand emanates from the decision of elevators to supply markets. In order to supply markets, these elevators must procure grain from farmers and other elevators located off river. These elevators do it through a pricing mechanism (the bid price). This allows the procurement of grain over a spatial area. We develop a model that explains these pricing decisions and link the decisions directly to output decisions of the barge shipping elevator. Our empirical work suggests that using this approach, barge quantities are responsive to price levels. Our estimates suggests that demand is relatively elastic with an elasticity estimates between –1.33 to -1.90. In addition, we find strong evidence that the output of firms is affected by the spatial distribution and characteristics of firms in the marketplace. In particular, the distance of the nearest competitor has a positive influence on both firm output (and, therefore transportation demands) and elevator gathering areas. To our knowledge, this is the first study to integrate the spatial properties of market areas into an empirical framework. Additionally, aggregating this work by pool, this research fits directly into the existing U.S. Army Corps of Engineers planning models currently used.

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LIST OF TABLES AND FIGURES

Table 1. Descriptive Statistics

Variable	Centile	Average
Annual Ton-Miles (thousand)	13,900	56,900
Barge Rate	.012	.011
Transportation Rate to Elevator	.089	.094
Alternative Rate	.128	.125
Firm Capacity (thousand)	574	1,850
Distance to Nearest Competitor	1.75	6.58
Area Capacity (thousand)	2,500	7,900
Number of Area Firms	4	5.25
Area Production (thousand)	41,600	58,400
Gathering Area	60	68.30

Table 2. Annual Output Regression Estimates

	OLS	**OLS**	**Fixed Effects by Area**	**Fixed Effects by Area**
	Log(Annual Ton-Miles)	*Log(Annual Ton-Miles)*	*Log(Annual Ton-Miles)*	*Log(Annual Ton-Miles)*
Log(Barge Rate)	-1.41**	-1.61***	-1.33**	-1.90***
	(0.583)	(0.608)	(0.661)	(0.697)
Log(Transportation Rate to Elevator)	-1.24**	-1.19**	-0.860	-1.10*
	(0.550)	(0.560)	(0.654)	(0.638)
Log(Alternative Rate)	-0.365	-0.126	-0.065	0.204
	(0.746)	(0.756)	(0.857)	(0.840)
Log(Capacity)	0.166	0.199	0.114	0.164
	(0.114)	(0.122)	(0.175)	(0.187)
% of Elevator Shipments that are Corn	1.86***	1.45***	1.62***	1.45***
	(0.409)	(0.461)	(0.466)	(.505)
Log(Distance to Nearest Competitor)		-0.068		0.787*
		(0.199)		(0.428)
Same Location Dummy		-0.144		0.709
		(0.508)		(0.768)
Log(Area Capacity)		-0.006		-0.147*
		(0.032)		(0.079)
Number of Firms in the Area		0.051		0.296*
		(0.063)		(0.164)
Dummy for Conglomerate Firms	0.969***	0.882***	0.646	0.752*
	(0.330)	(0.335)	(0.412)	(0.398)
Log(Area Production)		0.101*		0.088
		(0.054)		(0.070)
Constant	2.58	0.383	5.52	-0.128
	(2.943)	(3.385)	(3.582)	(4.678)
Observations	103	103	103	103
R-squared	0.3604	0.3963	0.5222	0.6022

A * indicates significance at the 10% level, a ** indicates significance at the 5% level, a *** indicates significance at the 1% level.

Table 3. Gathering Area Regression Estimates

	OLS *Log(Gathering Area)*	**OLS** *Log(Gathering Area)*	**Fixed Effects by Area** *Log(Gathering Area)*	**Fixed Effects by Area** *Log(Gathering Area)*
Log(Barge Rate)	0.118	0.185	0.370	0.398
	(0.230)	(0.232)	(0.235)	(0.262)
Log(Transportation Rate to Elevator)	-0.070	0.038	0.143	0.108
	(0.217)	(0.213)	(0.232)	(0.240)
Log(Alternative Rate)	-0.712**	-0.693**	-0.412	-0.382
	(0.294)	(0.288)	(0.304)	(0.316)
Log(Capacity)	-0.040	-0.027	-0.063	0.005
	(0.045)	(0.047)	(0.062)	(0.070)
% of Elevator Shipments that are Corn	-0.412**	-0.468***	-0.366**	-0.412**
	(0.161)	(0.176)	(0.166)	(.190)
Log(Distance to Nearest Competitor)		-0.085		0.280*
		(0.076)		(0.161)
Same Location Dummy		-0.095		0.529*
		(0.194)		(0.288)
Log(Area Capacity)		0.009		0.023
		(0.012)		(0.030)
Number of Firms in the Area		0.032		-0.055
		(0.024)		(0.062)
Dummy for Conglomerate Firms	0.357***	0.282**	0.375**	0.324**
	(0.130)	(0.128)	(0.146)	(0.150)
Log(Area Production)		0.007		0.008
		(0.020)		(0.026)
Constant	3.40***	3.66***	5.94***	4.51**
	(1.159)	(1.290)	(1.272)	(1.756)
Observations	103	103	103	103
R-squared	0.1977	0.2920	0.5131	0.5469

A * indicates significance at the 10% level, a ** indicates significance at the 5% level, a *** indicates significance at the 1% level.

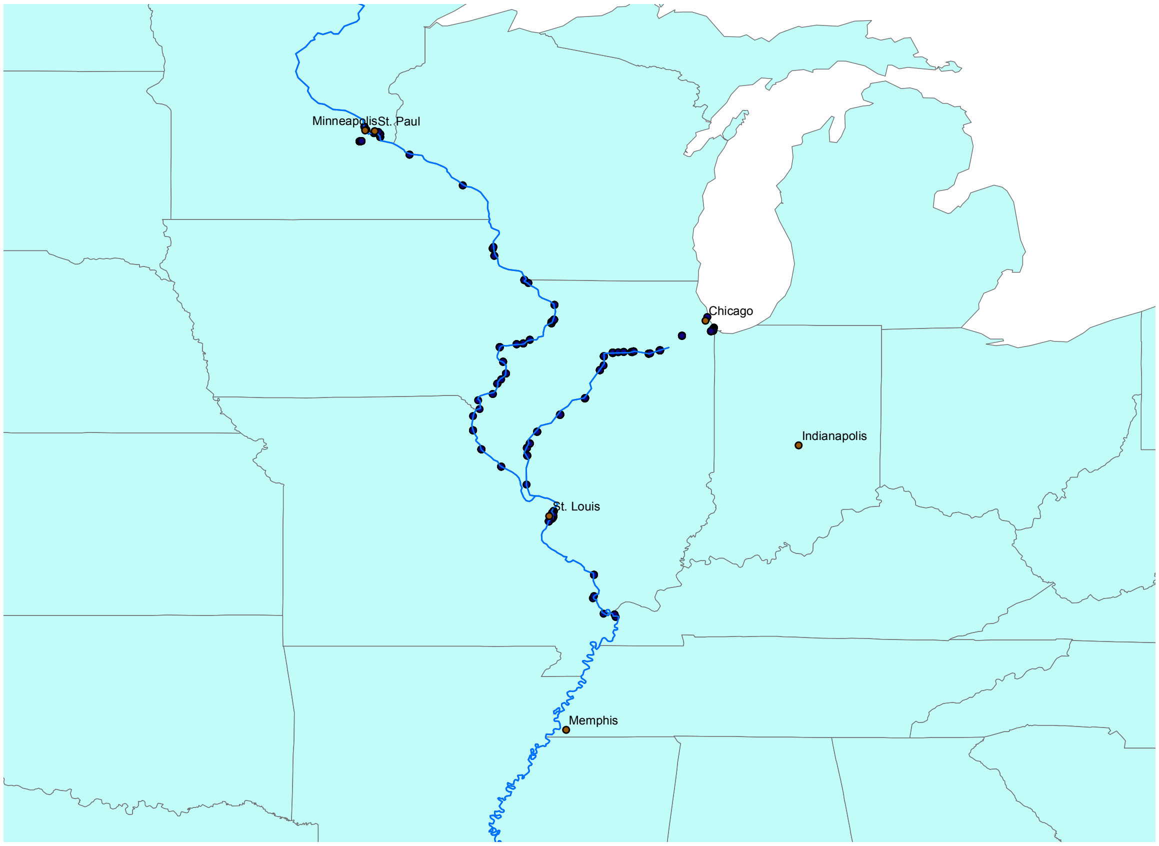

Figure 1: Barge Terminal Locations Shipping Grain

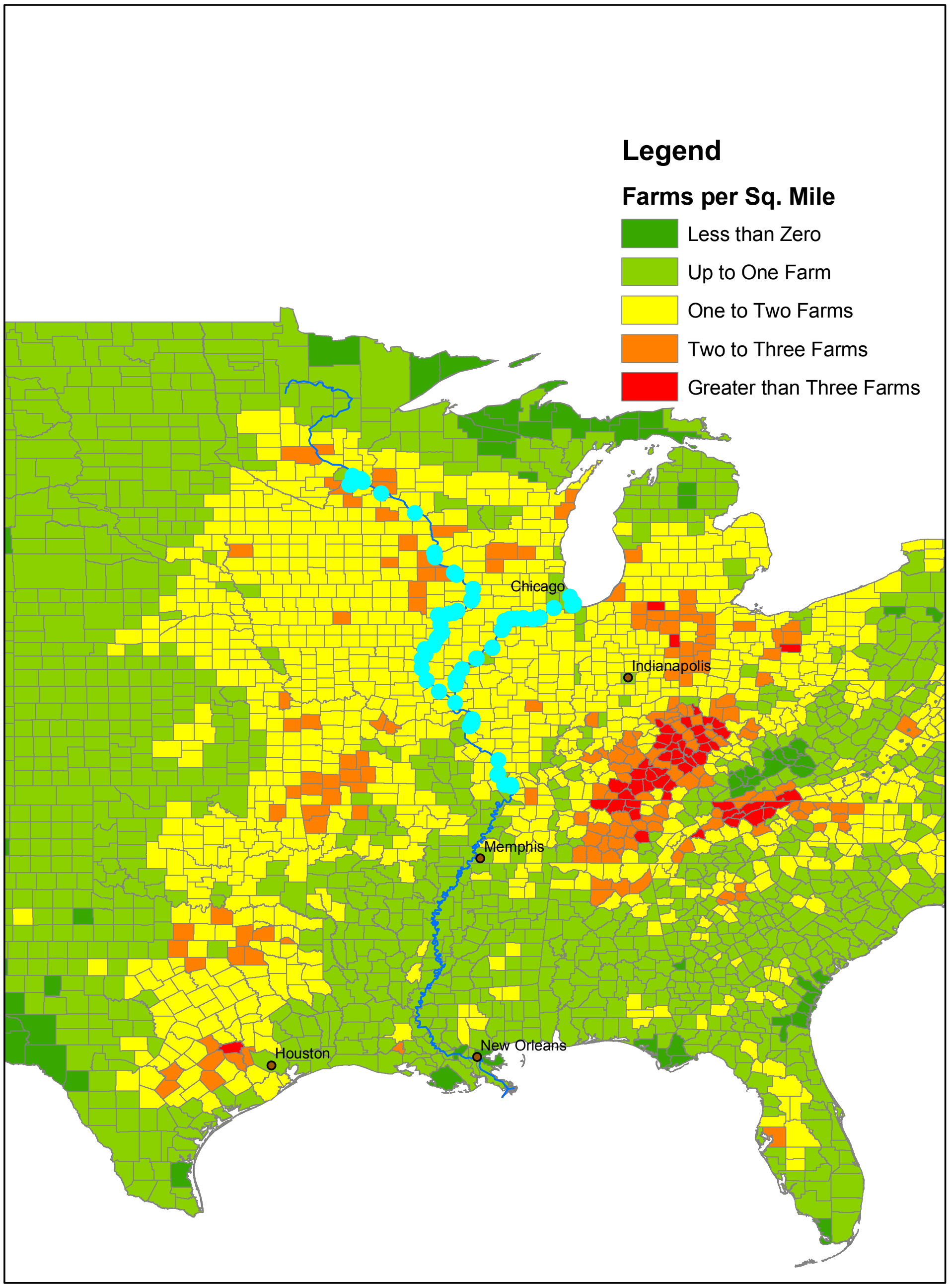

Figure 2: Farm Densities

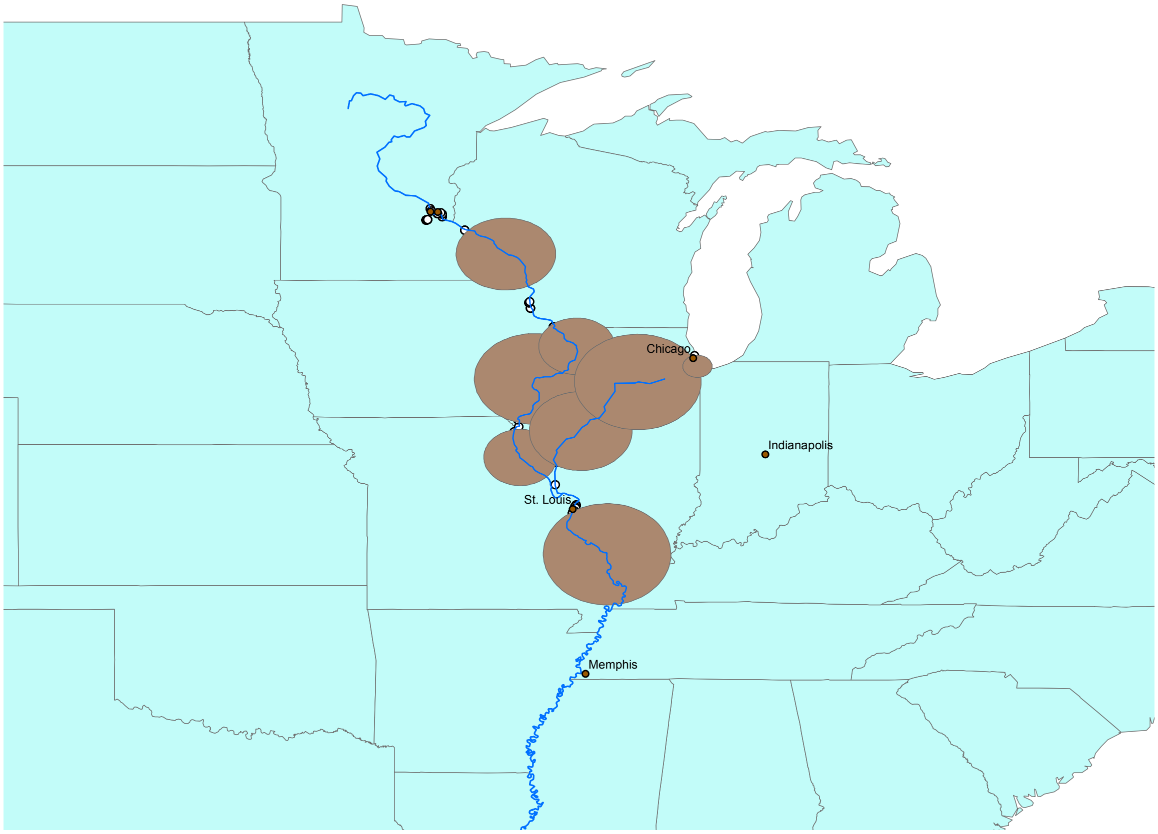

Figure 3: Median Gathering Areas

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The NETS research program is developing a series of practical tools and techniques that can be used by Corps navigation planners across the country to develop consistent, accurate, useful and comparable information regarding the likely impact of proposed changes to navigation infrastructure or systems.

The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting international and domestic traffic flows and how they may be affected by project improvements.
- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

As these models and other tools are finalized they will be available on the NETS web site:

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The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

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The Navigation Economic Technologies Program

July 31, 2005

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PATTERNS IN GEOGRAPHIC ELASTICITY ESTIMATES OF BARGE DEMAND ON THE UPPER MISSISSIPPI AND ILLINOIS RIVERS

US Army Corps of Engineers®

IWR Report 05-NETS-P-03

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

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The NETS program was overseen by Mr. Robert Pietrowsky, Director of the Institute for Water Resources.

July 31, 2005

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PATTERNS IN GEOGRAPHIC ELASTICITY ESTIMATES OF BARGE DEMAND ON THE UPPER MISSISSIPPI AND ILLINOIS RIVERS

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WORD COUNT: 2 Tables + 9 Figures + Words **=** 500 + 2,250 + 3,240 = 6794 words.

ABSTRACT: This paper investigates patterns in the demand for barge transportation along the inland waterway system. Non-parametric techniques including both rolling regression and locally weighted regressions are used to visually analyze the pattern of elasticity estimates along the river at the pool level. The results of these non-parametric approaches visually indicate that barge demand elasticity may be more elastic on both the southern and northern reaches of the river, while being more inelastic toward the center of the waterway system. Based on the non-parametric analysis, higher order elasticity terms are used to parametrically investigate the pattern of elasticity along the inland waterway system. Using the parametric approach, the same patterns of elasticity arise wherein demands are relatively more elastic on the northern and southern ends of the waterway system and relatively less elastic in the center.

INTRODUCTION

Transportation demand models and their empirical estimation have long been important from both an academic and a policy perspective. Of particular importance has been the estimation of transportation demand elasticity. Numerous studies have estimated this elasticity for various modes of public transportation including: automobile usage where the estimated elasticity is between .01 and 1.26, urban transit with an estimated elasticity between .01 and 1.32, airline travel with an estimated elasticity between .36 and 4.60, and rail travel with an estimated elasticity between .12 and 1.54 (1). Equally important has been the estimation of freight transportation, i.e. the movement of commodities. The elasticity estimates of these various modes are found to depend heavily upon the commodity being transported but with general elasticity estimates of: rail transportation with an estimated elasticity between .02 and 3.50 and motor carrier transportation with an estimated elasticity between .14 and 2.96 (1).

Recently, these models have been of particular importance to navigation planning practitioners who model barge demand in conducting their welfare analysis of navigation improvements. In particular, the Tow Cost (TCM) and the Ohio River Navigation Investment Model (ORNIM) models assume that barge demand is constant up to the least cost alternative transportation rate at which point all traffic switches from barge to the alternative mode. Alternatively, the ESSENCE model assumes that demand is not constant, but rather falls as the barge price increases until the same threshold point is reached at which point all traffic again switches from barge to the alternative mode.

With respect to barge transportation there have been numerous recently studies attempting to estimate the demand elasticity of barge transportation. Yu and Fuller estimate that barge demand for grain is inelastic with estimates between -.50 for the Mississippi River and -.20 for the Illinois River (2). Dager, Bray, Murphree and Leibrock meanwhile estimate the demand elasticity of barge demand for corn shipments to be between -.7 and -.3, again both inelastic (3). Train and Wilson use both revealed and stated preference data to analyze both mode and origin-destination changes as a result of an increase in the barge rate. Using this framework they estimate barge demand elasticities between -.7 and -1.4 (4).

Henrickson & Wilson estimate barge demand elasticity by explicitly controlling for the spatial characteristics of each grain elevators transportation decision (5). In doing this they find elasticity estimates between -1.41 and -1.90 which are much larger than the results found by Dager et al. (3) and Yu and Fuller (1), but similar to those found by Train and Wilson (4).

While Henrickson and Wilson do explicitly account for spatial characteristics affected grain elevators, they also implicitly make the assumption that barge demand elasticity is constant across the river. There are two main arguments for a non-constant elasticity across the river. First consider shippers located at the southern end of the Upper Mississippi River. Theoretically, is these shippers could be more responsive to changes in the barge rates because they have a shorter distance to the destination and could bypass the river by using more expensive alternative modes of transportation if the barge rate increased. Alternatively, shippers located at the northern end of the Upper Mississippi River may also be more responsive to changes in the barge rate because they have the longest distance to the downriver destination. These shippers may find it worthwhile to ship to an alternative destination (e.g. the Pacific Northwest) via a more costly mode if the barge rates increased.

In this paper an attempt is made to describe the effects of relaxing this assumption by allowing the estimated barge elasticity to vary along the river. Non-parametric approaches, both rolling regressions and locally weighted regressions, are used to estimate the approximate pattern of demand elasticity along the river. Using these results, we then use parametric approaches to estimating the barge elasticity along the river. Both our non-parametric and parametric results support the hypothesis that barge demands are relatively more elastic on the northern and southern ends of the river and relatively inelastic towards the center of the waterway system.

Section 2 provides a more complete background of the previous literature analyzing barge transportation demand. Section 3 presents the empirical strategies used to estimate geographically varying elasticity estimates. Section 4, outlines the data used for the analysis. Section 5 presents the results of our various geographically varying elasticity estimation techniques, while in Section 6 provides concluding comments.

BACKGROUND

Yu and Fuller estimate six separate grain barge demand equations for each of the Mississippi and Illinois Waterways. They find that the demand elasticity for barge transportation on the Mississippi River is approximately -.50 and on the Illinois River is about -.20. However, as they acknowledge themselves “The models estimated yield weak statistical results” (2). Indeed, many of their theoretically important variables are not statistically significant and reverse signs across their various specifications.

Dager et al. regress the tons of corn barged by month and by river section on the monthly price of corn in New Orleans less a proxy for local price less the monthly corn tariff, foreign grain demand, monthly or seasonal dummy variables, and the number of empty barges. Using this strategy they estimate the elasticity of barge demand for corn to be between -.7 and -.3 (3). Dager at al. also attempt to control for geographically varying elasticity estimates by estimating this equation for four separate sections of the river. However, it is unclear whether the four sections of river they chose appropriately segment of the river.

Train and Wilson use survey data and both stated and revealed data to analyze the effects of changes in both barge rates and barge transportation times on mode choices and origin-destination choices. They find that many shippers respond to even a small change in the current barge rate by changing either their mode of choice or their origin-destination choice. Further, they find that shippers are also responsive to barge transit time, but less so than to changes in the barge rate (4).

Henrickson and Wilson develop a theoretical model of barge demand from the perspective of port grain elevators. In this model, they are able to account for the spatial competition between these elevators. Using this model they estimate the responsiveness of port grain elevators located along the Mississippi and Illinois Rivers to barge rates in order to estimate barge demand elasticities. Using both OLS and pool specific fixed effects, they estimate barge demand elasticites of -1.4 to -1.9. However, as stated previously, they assume that these elasticity estimates apply to the whole length of the river, i.e. they assume a constant elasticity (5).

EMPIRICAL MODELS

Henrickson and Wilson develop a theoretical framework whereby grain elevators choose their bid price, and subsequently their quantity, so as to maximize their profits (5). The profit maximizing quantity is found to be a function of the price at the destination, the transportation rate, service induced costs, and procurement/processing costs determinants:

$$Q^*_{md} = Q^*_{md}(P_d, t_{md}, s_{md}, c, D, y)$$

Using this equation, Henrickson and Wilson then develop an empirical model where quantity shipped is regressed on: the barge rate, the rate from farmers to the elevator's location, the alternative mode rate, firm capacity, the distance to the nearest competitor, the number of firms in the area, the capacity of the firms in the area, area production, origin mile, and a dummy variable to denote elevators owned by large conglomerate firms.

In this study, we use the same empirical model as Henrickson and Wilson, but we relax the assumption of constant elasticity to examine whether barge demand elasticity varies across the river.

To examine the pattern of barge demand elasticity along the river, two non-parametric techniques: rolling regressions and locally weighted regressions are used to describe the patterns of estimates. In each of these non-parametric models, the data are ordered in ascending order according to river mile. The estimation equation developed by Henrickson and Wilson is then run on subsets of the data, the difference between the rolling regressions model and the locally weighted regressions model being how the subset is used in the estimation process.

In the rolling regressions model, the estimation equation, as specified above, is run on a "window" of data. The size of the window is arbitrary, and thus various specifications of the window size are run. Essentially, the barge demand equation is run on the first x observations and the demand elasticity is recorded (the first x observations correspond to the x shippers located furthest south, x is our window size). Note that x is arbitrarily chosen, and the only restriction on it is that it must be large enough to estimate the equation. The barge demand equation is then run on observations 2 through x+1 and the demand elasticity of this equation is then recorded. The equation is then run on 3 through x+2, 4 through x+3, etc. In essence, we are taking a window of size x and moving it along the river one position at a time estimating the demand elasticity in each window location.

The second non-parametric technique used to examine elasticity over space is a locally weighted regression developed by Cleveland (6). This technique is similar to the rolling window technique with one notable difference. Again, one must specify a window size in which the demand equation will be run and again move the window up the river one position at a time. The key difference is that the observations in the window are weighted such that the middle position gets the highest weight and each position away from the middle gets subsequently lower weights. For example, if a window size of 5 was specified, the middle position would be the 3rd observation in the window and it would receive a weight of 1, indicating that it is fully weighted. Positions 2 and 4 would receive a weight of .89 each, positions 1 and 5 would receive a weight of .35 each, and positions 0 and 6 would receive a weight of 0 meaning that they are not included in the regression. Note that this weighting scheme is the tricube weight proposed by Cleveland (6). Weighted least squares is then used to estimate the demand elasticity for the given middle location and window size. The estimated elasticity is then recorded and the window is moved up the river one location and estimated again.

To further examine the patterns of barge demand elasticity along the river, we estimate different parametric specifications of the Henrickson and Wilson empirical model (5). In particular, interactions between barge rates and different polynomials up to three powers are used in an attempt to capture the relevant patterns.

DATA

The majority of data used for this analysis came from the Tennessee Valley Authority (TVA). The TVA collected these data during two sets of personal interviews of barge terminals located along America's inland waterways. According to the U.S. Army Corps of Engineers' Port Series database, there are currently almost 200 elevators located along the Mississippi and Illinois Rivers whose stated purpose is the shipment of grain. These elevators can be seen in Figure 1.

For this study, we use the same subset of data as Henrickson and Wilson (5). In particular, we analyze the 103 grain elevators located on the Upper Mississippi and Illinois rivers as shown in Figure 2. Note that we matched the TVA data with the USACE Port Series to obtain these terminal locations.

During the course of their interviews, the TVA collected information regarding each location's annual tons shipped, commodities shipped, barge charges, truck transfer charges, the termination of the shipments, their average gathering area of product to be shipped, and alternative routes that they could have sent that shipment if not by barge.

These data are supplemented with crop yields per acre and harvest levels at the county level from USDA.

Variables

The variables included in our empirical model come directly from Henrickson and Wilson (5). Our dependent variable is the *barge rate* which is defined as the rate per ton-mile of the barge movement. Our independent variables include: the *transportation rate from the farmer to the elevator* which is defined as the rate per ton-mile of using truck or rail to transport the commodity to the river terminal facility (i.e., in the context of the model developed by Henrickson and Wilson, it is the farmer's transportation cost); the *alternative rate* is the rate per ton-mile of the most common alternative to shipping down the river; *distance to nearest competitor* is the distance to the nearest competitor; *capacity* is the capacity in bushels of the elevator; *number of firms in area* in the number of competing elevators on the same bank of the same pool (pool being defined as the area between any two locks); *capacity of firms in area* is the capacity of the other firms in the same pool on the same bank; *area production* is the average production of the commodity in the county and bordering counties; and the *dummy variable for large conglomerate firms* is a dummy variable equal to 1 if the shipper is one of the six conglomerate firms in our sample. Summary statistics of each of these variables are provided in Table 1.

These statistics suggest there is considerable variation in annual ton-miles shipped. That barge rates per ton-mile are, as expected, much smaller than alternatives (rail and truck). Rates inbound to the shipping elevator are approximately 7 time higher than the barge rates, but much less than the alternative rate, owing to shorter distances. Firm capacity and area capacity vary quite a bit from elevator to elevator. The distance between elevators is about 1.75-6.5 miles, while the number of firms in the same area appears to be approximately 4. There also appears to be considerable variation in the area production of crops. Finally, the gathering area (the distance of inbound shipments) has a median value of 60 miles and an average value of about 68.3. Further, a simple regression of gathering area and river mile indicates that gathering areas increase with river mile, and a 100 mile increase in river mile increases gathering areas about 4 miles. From the lower reaches of the river to the most northern areas, this suggests a difference in gathering area of about 33 miles.

RESULTS

Rolling Regressions

We run the rolling regressions technique over 3 different window sizes (x): 30, 40 and 50. Figures 3, 4 and 5 show the results of using the rolling regressions model with each of these window size specifications. Notice that as the window size increases, the “bumpiness” of the graph decreases. This is because as we add more observations to each individual regression in the rolling regression technique we approach the estimates obtained when running the estimation equation on the total sample.

Inspecting Figures 3, 4 and 5 it appears that elasticity is more inelastic the further up the river an elevator is located. However, there also appears to be a pattern consistent with the elasticity being most inelastic in the center of our range and more elastic towards the top and bottom of the range that coincides with previous explanation of why elasticity may not be constant. That is, elevators located at the northern end of the river may be more responsive to barge rate changes because they have the longest distance down river and therefore may choose to ship to an alternative market such as the northwest; while elevators located on the lower portion of the river may choose to bypass the river and use rail instead given their shorter distance to their destination.

Locally Weighted Regressions

We run the locally weighted regressions technique over 3 different widow sizes (x) as well: 40, 60, and 80. We use larger window sizes with the locally weighted regressions technique than we did with the rolling regressions because observations are weighted less as one moves away from the center observation therefore we can use more information (more observations) without losing the ability to visually gain information regarding what is happening at the center of the specified window. Figures 6, 7 and 8 show the results of using the locally weighted regression model with each of these window size specifications. Again, notice that as the window size increases, the “bumpiness” of the graph decreases. Also notice that Figures 6, 7 and 8 are much smoother than Figures 3, 4 and 5 due to its larger sample size.

Visually, Figures 6, 7 and 8 seem to show more elastic barge demand along the southern and northern parts of the river with less elastic demand in the center. As with the results of the rolling regression model, this conforms to our previous story and indicates that the pattern of barge demand elasticity is one where demand is inelastic in the middle of the waterway system and more elastic towards the upper and lower ends of the system.

Parametric Specifications of Elasticity Along the River

The results of various specifications of elasticity estimates based on the non-parametric pattern of Figures 3 through 8 are presented in Table 2 and in Figure 5.

Figure 5 graphically shows the estimates of each of our varying coefficient models. These results indicate that shippers located along the southern section of the waterway system appear to be more responsive to changes in the barge rate, while shippers located further up the river appear to be less responsive. The cubic model which allows for a second switch in the elasticity trend indicates that the elevators located at the extreme north end of the river do tend to be more elastic than their counterparts located towards the center of the river.

Using both non-parametric and parametric techniques we have developed a consistent picture with regard to the pattern of barge demand elasticity along the Upper Mississippi and Illinois Rivers. Each of our specifications indicates that barge demand is more elastic for grain elevators located on the northern and southern ends of the river while barge demand is more inelastic for elevators located towards the center of the waterway system. This finding is consistent with the idea that elevators located towards the middle of the waterway system have fewer options (than elevators located at the northern and southern ends of the waterway system) with regard to both where and how they ship their commodities.

CONCLUSION

This paper expands upon the Henrickson and Wilson (5) framework investigating the pattern of barge transportation demand elasticity along the inland waterway system. We first use the non-parametric techniques or rolling regressions and locally weighted regressions to visually analyze the pattern of elasticity estimates along the river. We then use higher order elasticity terms to parametrically examine the pattern of barge demand elasticity. Both our non-parametric and parametric approaches indicate the presence of the same pattern of barge demand elasticity along the Upper Mississippi and Illinois River. That is that barge demand is more elastic for elevators located on both the northern and southern ends of the waterway system while demand is more inelastic for elevators located towards the center of the waterway system. Furthermore, this pattern is consistent with the idea that elevators located towards the center of the waterway system have less options with regard to where and how to ship their commodities. One possibility for future research, which we are perusing, is to extend the dummy variable approach of both Yu and Fuller (2) and Dager et al. (3) by endogonizing the choice of dummy variables using the method developed by Hansen (7) and allow the data to determine what dummy variables should be specified, and use this model to estimate barge demand elasticities along the Upper Mississippi and Illinois Rivers.

ACKNOWLEDGEMENTS

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LIST OF TABLES AND FIGURES

TABLE 1 Descriptive Statistics

Variable	Centile	Average
Annual Ton-Miles (thousand)	13,900	56,900
Barge Rate	.012	.011
Transportation Rate to Elevator	.089	.094
Alternative Rate	.128	.125
Firm Capacity (thousand)	574	1,850
Distance to Nearest Competitor	1.75	6.58
Area Capacity (thousand)	1,413	4,788
Number of Area Firms	4	4.1
Area Production (thousand)	41,600	58,400
Gathering Area	60	68.30

TABLE 2: Parametric Geographically Varying Elasticity Estimates

Model	Barge Rate Estimate	Barge Rate Interacted with River Mile Estimate	Barge Rate Interacted with River Mile Squared Estimate	Barge Rate Interacted with River Mile Cubed Estimate	Joint Significance of Elasticity	Joint Significance of Non-Constant Terms
Constant Elasticity	-1.90*** (.706)					
Linear Elasticity in River Mile	-2.54** (1.13)	.002 (.003)			F = 3.87**	F = .52
Quadratic Elasticity in River Mile	-1.65 (1.40)	-.005 (.007)	.00002 (.00002)		F = 2.97**	F = .84
Cubic Elasticity in River Mile	-1.73 (1.41)	-.01 (.01)	.00007 (.00006)	.00000007 (.00000008)	F = 2.42**	F = .82

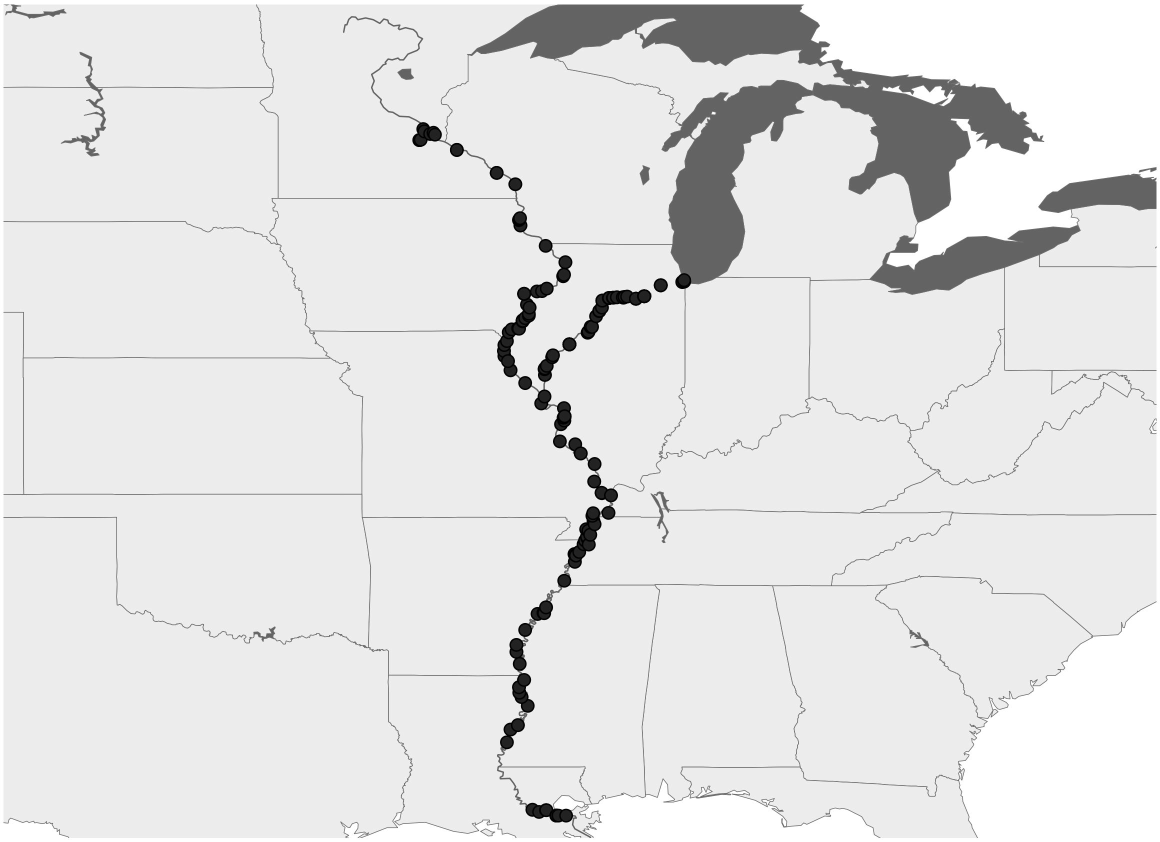

FIGURE 1 Barge Terminal Locations of Grain Shippers on the Mississippi and Illinois Rivers

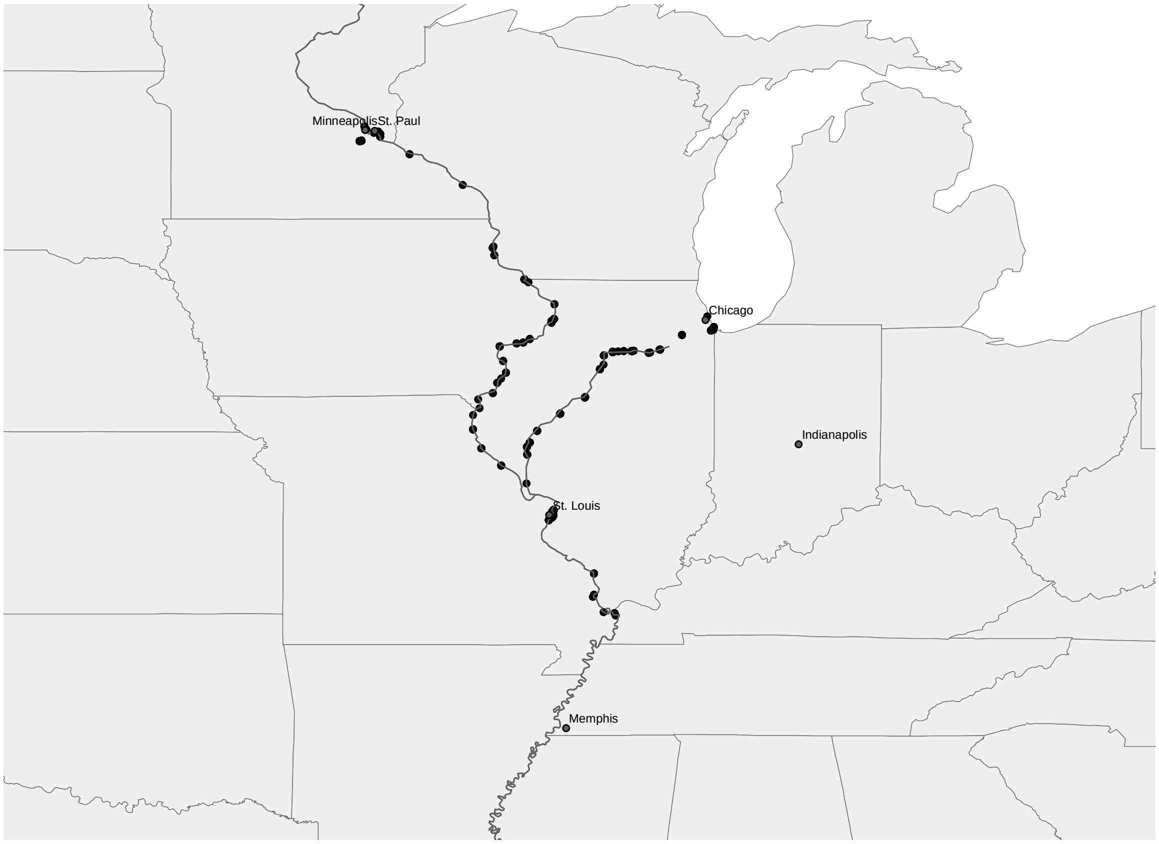

FIGURE 2 Barge Terminal Locations Shipping Grain From TVA Survey

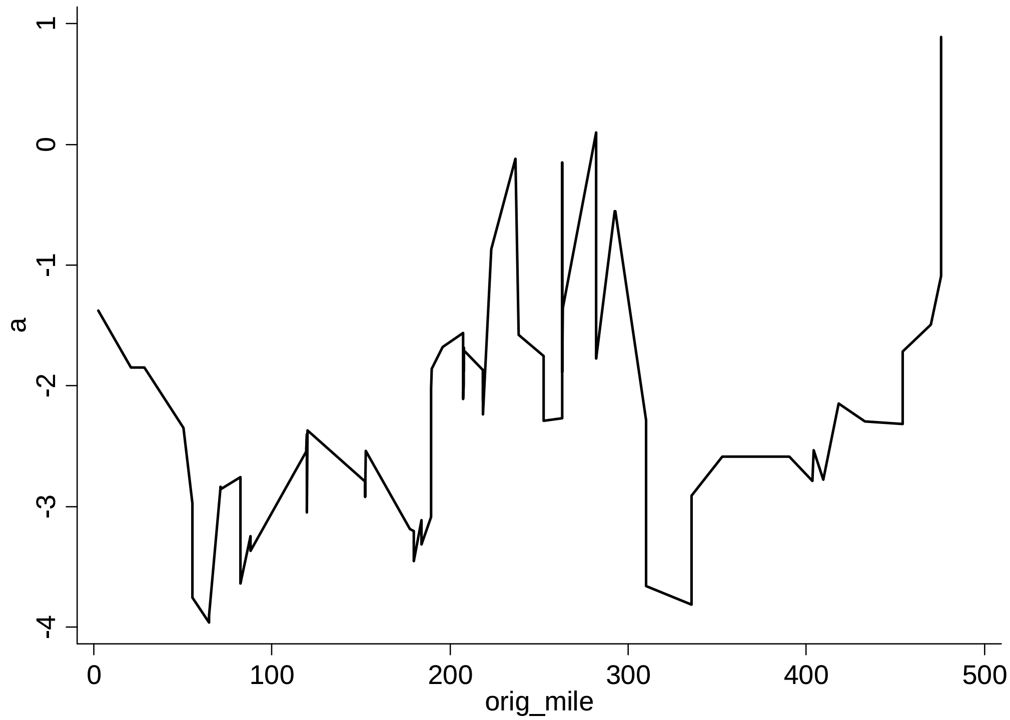

FIGURE 3: Rolling Regressions Estimates with Window Size 30

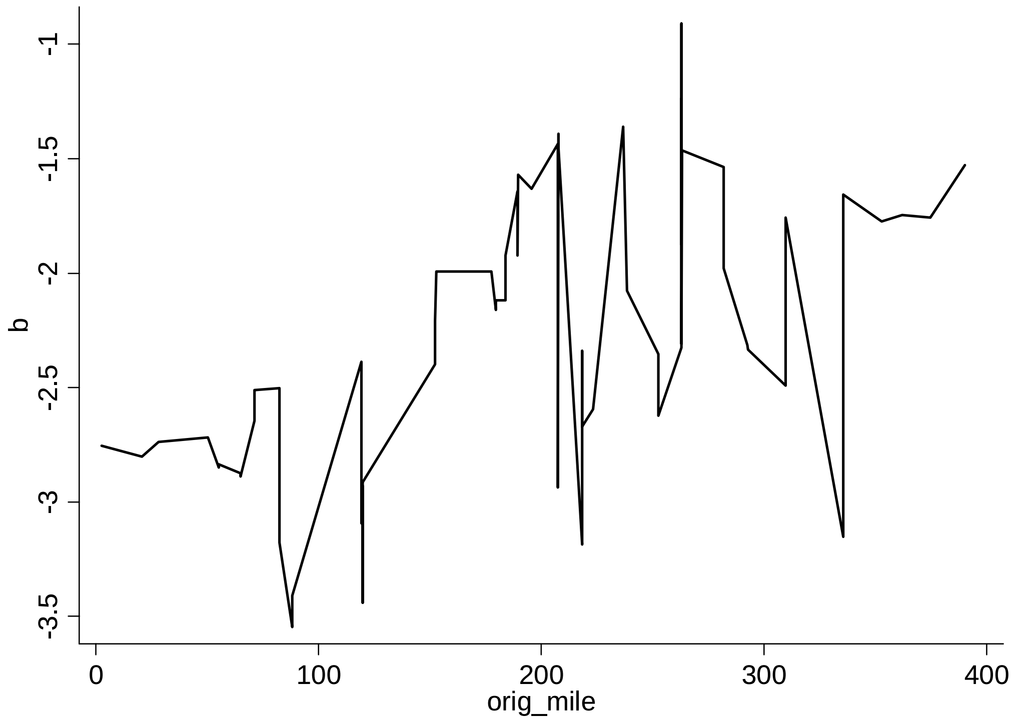

FIGURE 4: Rolling Regressions Estimates with Window Size 40

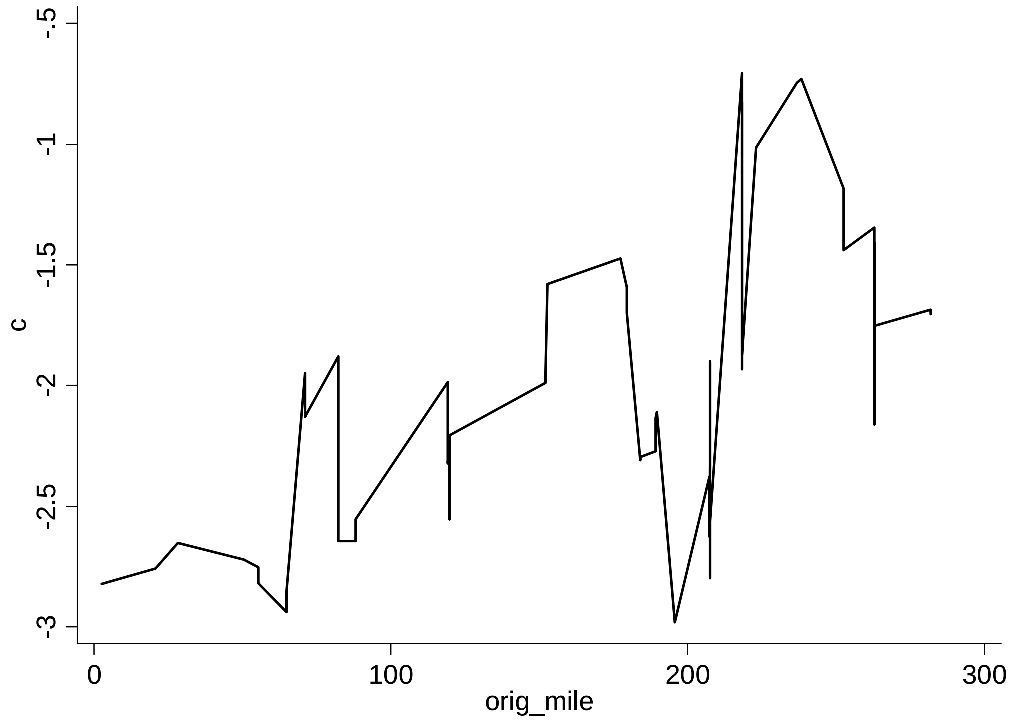

FIGURE 5: Rolling Regressions Estimates with Window Size 50

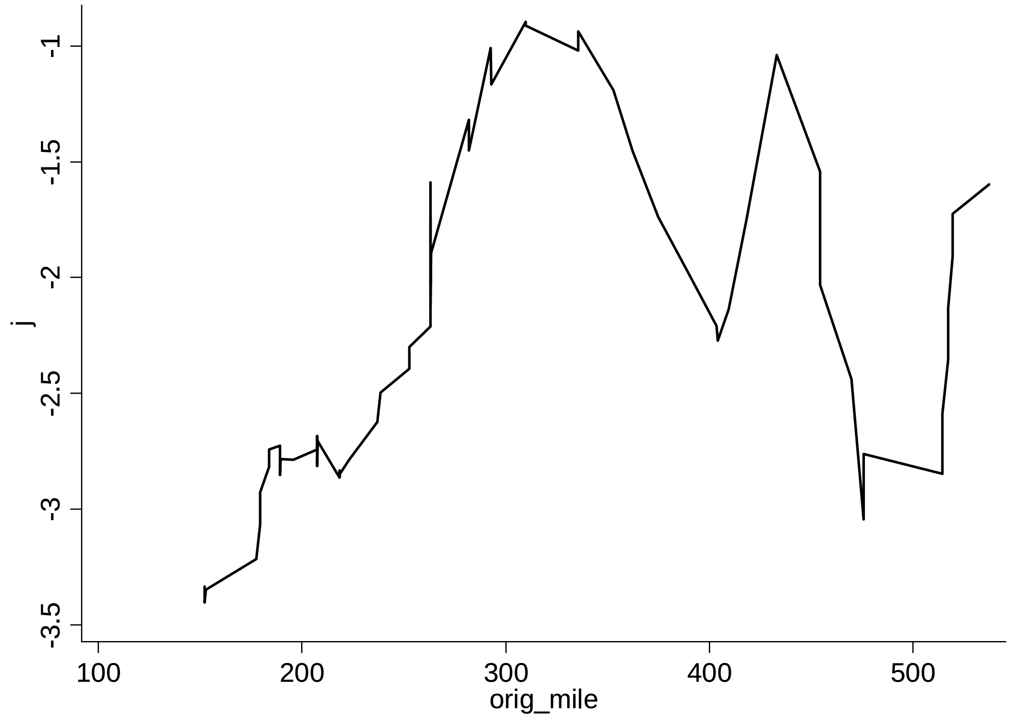

FIGURE 6: Locally Weighted Regressions Estimates with Window Size 40

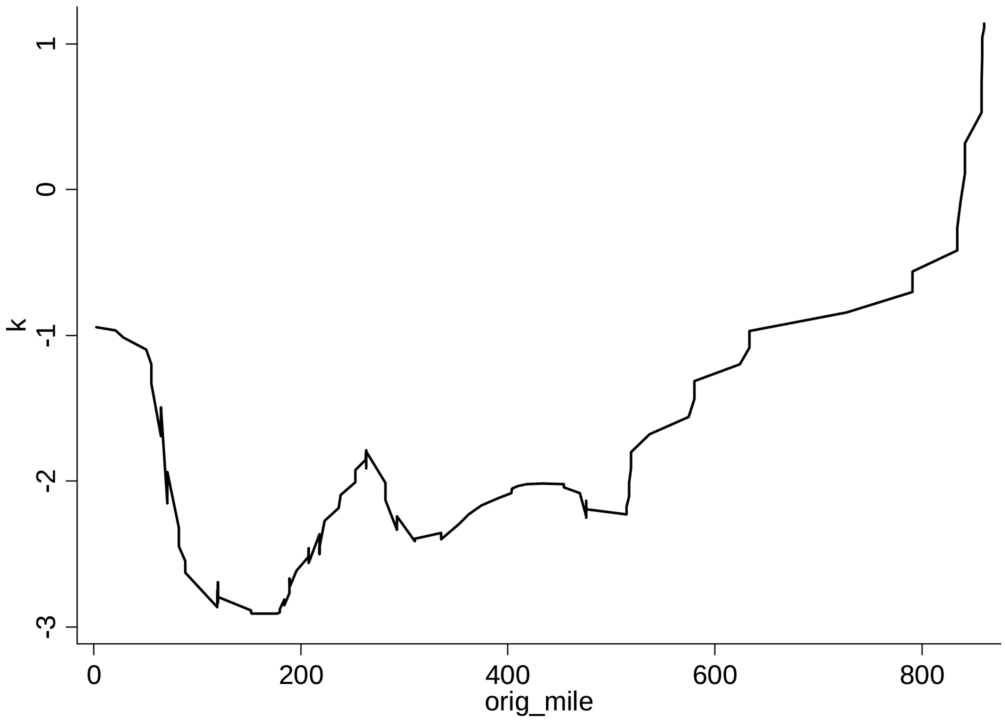

FIGURE 7: Locally Weighted Regressions Estimates with Window Size 60

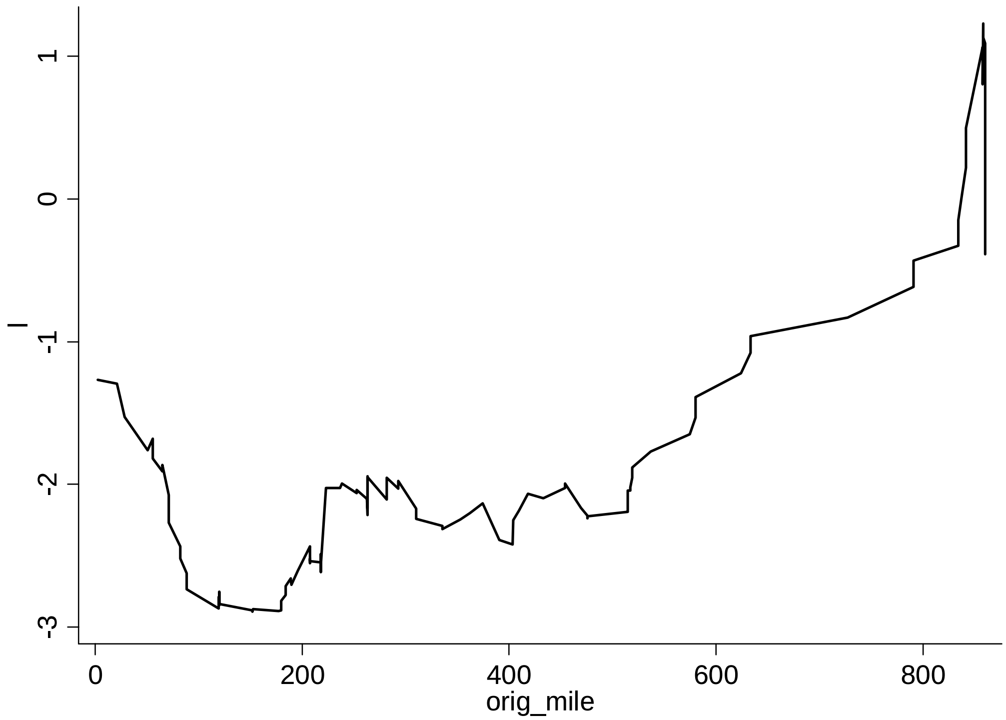

FIGURE 8: Locally Weighted Regressions Estimates with Window Size 80

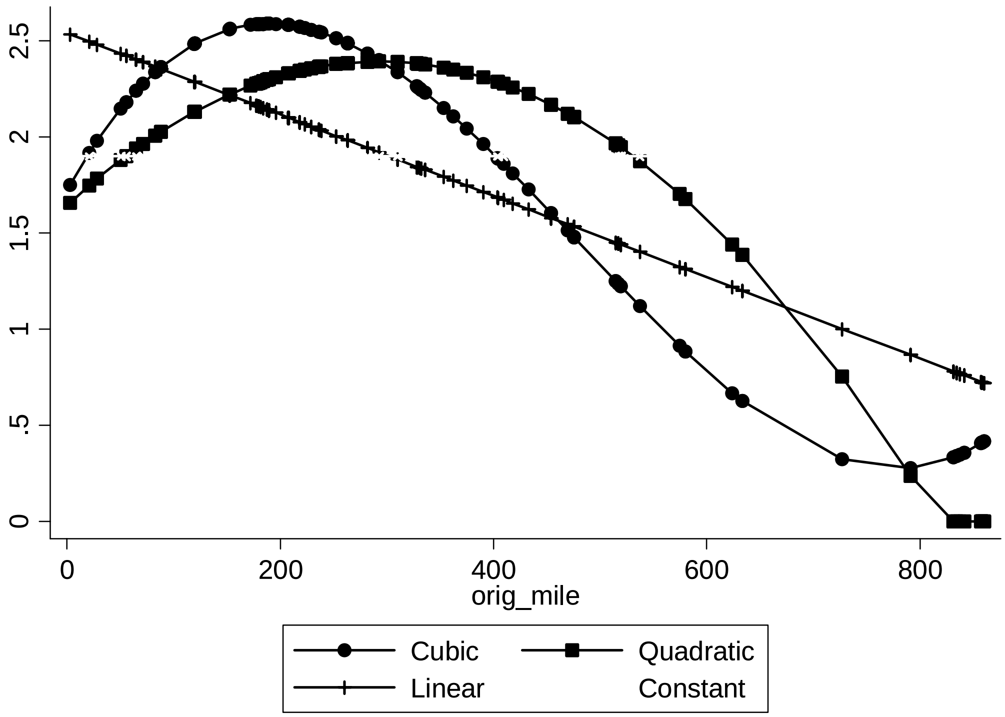

FIGURE 9: Parametric Geographically Varying Elasticity Estimates

The NETS research program is developing a series of practical tools and techniques that can be used by Corps navigation planners across the country to develop consistent, accurate, useful and comparable information regarding the likely impact of proposed changes to navigation infrastructure or systems.

The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting international and domestic traffic flows and how they may be affected by project improvements.
- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

As these models and other tools are finalized they will be available on the NETS web site:

http://www.corpsnets.us/toolbox.cfm

The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

http://www.corpsnets.us/bookshelf.cfm

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The Navigation Economic Technologies Program

January 1, 2005

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A SURVEY OF THE FREIGHT TRANSPORTATION DEMAND LITERATURE AND A COMPARISON OF ELASTICITY ESTIMATES

US Army Corps of Engineers®

IWR Report 05-NETS-R-01

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

For further information on the NETS research program, please contact:

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The NETS program was overseen by Mr. Robert Pietrowsky, Director of the Institute for Water Resources.

January 1, 2005

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A SURVEY OF THE FREIGHT TRANSPORTATION DEMAND LITERATURE AND A COMPARISON OF ELASTICITY ESTIMATES

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FREIGHT TRANSPORTATION DEMAND LITERATURE
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January 2005

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EXECUTIVE SUMMARY

This survey provides a general overview of the methodology and results of several aggregate and disaggregate studies of freight transportation demand. The survey provides a detailed look at neoclassical “aggregate” models and disaggregate “choice” models based on McFadden’s random utility model. After presentation of these different methodologies to estimate freight demands, the study concludes with a comparison of elasticity estimates across modes and methods. The survey concludes with a discussion possible improvements to demand studies. This final discussion follows the suggestions of Oum et al. (1992) and leads to a recommendation of how these suggestions apply to modeling inland waterway transportation demand.

TABLE OF CONTENTS

I. INTRODUCTION

Transportation economics is "an applied area of economics that is concerned with the efficient use of society's scarce resources for the movement of people and goods from an origin to a destination" (McCarthy, 2001). Studies of transportation economics have been documented as early as 1840[1]. The first studies covered such topics as pricing of transportation infrastructure, congestion of roads, and optimal pricing of public transportation facilities (Winston, 1985). In his survey of developments in transportation economics, Winston (1985) discusses the ideas developed in these studies that are still widely used today in analyzing transportation problems. These ideas include Ramsey pricing (Dupuit, 1844), economies of scope and joint production (Wellington, 1877), and economies of scale (Lorenz, 1916). Since the appearance of these early transportation studies, countless others have analyzed issues in transportation economics. This paper focuses on the empirical transportation demand literature.

Transportation demand modeling is complicated by a number of characteristics that are central to the transportation industry. Small and Winston (1998) highlight some of these characteristics. These include: (1) the interrelated decisions of transportation, (2) the large number of distinct services differentiated by location or time (spatial and temporal aspects), and (3) the shipper's sensitivity to service quality (quality indicators include frequency, route coverage, reliability and comfort).

Empirical evaluations of these characteristics motivate many transportation demand studies. In particular, demand studies have based work on the mixed continuous discrete decisions of shippers (mode, location, and quantity) to evaluate relative import of factors

[1] Early studies of transportation economics include Ellis (1840), Dupuit (1844,1849), Wellington (1887),

important to choosing a transportation mode. Often there is a focus on the role of reliability and travel time in shippers' decisions and/or the influences of input or output price changes on firm's decisions (McCarthy, 2001). These estimates can be used to forecast the effect of various policy measures on transportation markets or individual firms and to evaluate the competitiveness of alternative modes of transportation.

In Section II we provide a general overview of the literature pertaining to estimation of transportation demand. Section III provides a comparison of the elasticity estimates from the studies discussed in Section II. Section IV concludes our study with a discussion of possible improvements to studies of transportation demand, and their application to inland waterway transportation demand studies.

II. LITERATURE REVIEW

Most of the studies of transportation demand from the last thirty years focus on estimation issues. While there is a wealth of passenger demand studies, the focus in this paper is on freight demand. This literature separates into two general categories: studies that employ aggregate data and those that employ disaggregate (shipper) data. We first turn to the aggregate models which played a key role in prompting the development of the more sophisticated disaggregate models. Most of the recent literature tends to use primarily disaggregate data and models based on shipper choices.

II.1. Aggregate Demand Models

Aggregate demand models use data that describe the behavioral aspects of a large group

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Pigou (1912), Lorenz (1916), and Knight (1924), to name a few.

of shippers (Small and Winston, 1998). There are two classes of aggregate demand models, modal split models and neoclassical aggregate demand models. The main difference between the two classes of models is the degree of behavioral assumptions embedded in each. The aggregate modal split models contain few behavioral aspects and hence are heavily criticized,[2] and this motivates the development of the neoclassical aggregate demand model.

The neoclassical aggregate demand models incorporate more of the behavioral aspects of groups of shippers. Small and Winston (1998) note that the neoclassical models based on standard microeconomic theory tend to be more satisfactory than the models not founded in theory. Another major benefit of the neoclassical models is the ability to use flexible functional forms in estimation. A very restrictive, linear, functional form is commonly used in modal split models. Examples of the neoclassical aggregate demand models are surveyed below.

Neoclassical Aggregate Demand Models

Oum (1979) identifies several weaknesses of existing demand models such as the use of restrictive functional forms, ad hoc[3] specifications of the model, the exclusion of service-quality attributes, and the use of highly aggregated data over heterogeneous commodities. He measures the price and quality responsiveness of demand using a derived demand model. Freight transportation demand is modeled as an input to a shipper's production and distribution activities.

[2] Winston (1985) identifies these articles as Perle (1964), McLynn and Watson (1967), Quant and Baumol (1966), Boyer (1997), and Levin (1978). These aggregate modal split models attempted to determine the number of trips or tonnage that were allocated between a given set of modes, over a cross section of city pairs, on the basis of relative travel times and costs among modes, or on the basis of characteristics of commodities that are transported (Winston, 1985).

[3] Ad hoc refers to the arbitrary specification of models without regard to the underlying production and

The formulation of the model is based on duality theory, or the relation between production and cost functions.[4] Thus, instead of imposing restrictions on the model by specifying a functional form, Oum derives a link-specific unit transport cost function for shippers as a function of freight rates, service quality attributes of various modes, and the distance of the link. A link is a section of a shipper's transportation network. The author specifies the cost function as a translog[5] and applies Sheppard's lemma[6] to the cost function to obtain the share-of-expenditure functions for rail and truck modes.

The data used include eight different commodity groups and consist of the distance of each link, total tons moved, average freight rate, transit time and its variability by mode on each link. All data employed were gathered for 1970 and taken from the Canadian Freight Transport Model database.

Oum develops three alternative models: (1) a general model, (2) a model with mode-specific hedonic aggregators and (3) a model with identical hedonic aggregators. The first model derives the cost function as a function of freight rates and quality attributes of various modes and the distance of the link. In the second model, a shipper bases his choice of mode on prices adjusted for quality variations. The last model assumes that the shipper chooses a mode using a comparison of the true contents of quality attributes. That is, the shipper views a mode not as a physical entity but rather as a set of attributes. Oum estimates the three models for each

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distribution technology of the shipper.

[4] Duality theory implies that if producers minimize input costs in producing given outputs, and if factor prices are exogenous, then the cost function contains the information needed to describe the corresponding production function, and vice versa.

[5] A translog function is a linear combination of all possible first and second order terms in the logarithms of independent variables.

[6] Sheppard's lemma states that a small increase in the price of an input increases cost by an amount equal to the use of that input. For a greater detailed discussion of Sheppard's lemma see Sheppard (1953) or Oum (1979).

of the seven commodity groups. Then, he performs hypotheses tests to determine if speed and reliability variables are significant and chooses the best model for each commodity.

Using the estimates, elasticities of substitution between modes and the elasticity of demand for a mode with respect to its own or the other mode's freight rate and speed can be estimated. A summary of the estimated elasticities for rail and truck modes in Canada is presented in Table II.1.1. Oum finds that the elasticity of substitution between rail and truck is lowest for lumber, 1.04, while that for other commodities ranged between 1.40 and 1.57. These measures of elasticity indicate high substitutability between modes for most commodities; implying that a one percent increase (decrease) in rail freight rates would cause a more than one percent increase (increase) in the use of truck transportation and vice versa. The truck mode is less price elastic than rail mode for all commodities except for chemicals and fuel oils, and the price and quantity elasticities of demand vary substantially across commodities.

Table II.1.1

Comparison of Freight Elasticities for Canada[a]

Commodity Group/ Elasticities	Fruits, Vegetables & edible foods	Lumber, including flooring	Chemicals	Fuel oil except gasoline	Refined petroleum products	Metallic Products	Non-metallic products
Elasticity of rail-truck substitution	1.458	1.044	1.57	1.429	1.4	1.508	1.539
Compensated elasticity rail wrt rail freight rate	-1.006	-0.5324	-0.6282	-0.3858	-.9560	-1.176	-1.047
Compensated elasticity truck wrt truck freight rate	-0.4522	-0.5116	-0.942	-1.043	-0.4499	-0.3318	-0.4925
Ordinary elasticity rail wrt rail freight rate	-1.037	-0.5814	-0.6882	-0.4588	-0.988	-1.198	-1.079
Ordinary elasticity truck wrt truck freight rate	-0.5212	-0.5626	-0.982	-1.07	-0.5179	-0.4098	-0.5605
Compensated elasticity rail wrt rail speed	0.1348					0[b]	0.2693
Compensated elasticity rail wrt truck speed	-0.9016					-1.1491	-1.286
Compensated elasticity truck wrt rail speed	-.606					0[b]	-0.1267
Compensated elasticity truck wrt truck speed	0.4063					0.3232	0.6049
Compensated elasticity rail wrt reliability of rail speed	0.0342					0.1705	0.0868
Compensated elasticity rail wrt reliability of truck speed	-2.4354					-1.1454	-2.5350
Compensated elasticity truck wrt reliability of rail speed	-0.0154					-0.481	-.0408
Compensated elasticity truck wrt reliability of truck speed	1.0947					.3232	1.1924

Friedlaender and Spady (1980) follow a similar methodology. They present a

[a] *Source* Oum (1979b, table 3, p. 477)
[b] Values not significantly different from zero.

neoclassical aggregate demand model for freight transportation that uses Sheppard's lemma to derive an input demand equation from a firm's cost function. Their study yields the input share equations for truck and rail service, and the estimated input cost shares. The input share equations then provide own-price and cross-price elasticities of demand for truck and rail modes. Freidlaender and Spady use the year 1972 cross section of 96 manufacturing industries to estimate the input share equation for truck and rail service.

Table **II.1.2** displays the own-price and cross-price elasticities of demand by mode and commodity group. The own-price elasticities for rail vary from -1.681 for stone, clay, and glass to -3.547 for electrical machinery.[7] The own-price elasticities of demand for truck, however, vary considerably less and range from -1.001 for food products to -1.547 for wood products. The cross-elasticities are quite low and range between -0.129 and 0.025.

Notes: Elasticities evaluated at means of variables

[7] An elasticity with absolute value greater than one implies that a one percent change in the price results in a more than a one percent change in demand. The positive elasticity implies a change in the same direction while the negative sign implies changes in the opposite direction (if one increases the other decreases).

Table II.1.2

Elasticities of Demand for Freight Rail and Road Freight[a]

Elasticities/ Commodity Groups	Rail price elasticities	Truck price elasticities	Rail wrt truck rates elasticities	Truck wrt rail rates elasticieties
Food products	-2.583	-1.001	-0.023	0.004
Wood and wood products	-1.971	-1.547	-0.050	-0.129
Paper, plastic & rubber products	-1.847	-1.054	0.007	0.003
Stone, Clay &glass products	-1.681	-1.031	0.025	0.016
Iron & steel products	-2.542	-1.083	-0.053	-0.013
Fabr. metal products	-2.164	-1.364	-0.059	-0.099
Non-electrical machinery	-2.271	-1.085	-0.032	-0.010
Electrical machinery	-3.547	-1.230	-0.151	-0.061

Summary of Neoclassical Aggregate Demand Models

Although neoclassical aggregate demand models integrate behavioral aspects of shippers and use flexible functional forms, and they have a clear advantage over the early modal-split models, the neoclassical models are not without their shortcomings. One of the disadvantages of the neoclassical approach is the use of aggregate data, or averages, which can suppress a significant amount of fruitful information. These models make it difficult to capture variation in decision-maker's characteristics and may over or understate the sensitivity of demand to price

[a] *Source* Freidlaender Spady (1980, table 2, p. 439).
Notes Based on 5 regions in the USA over 1972.

and service qualities. This in turn may result in flawed inferences pertaining to policy variables and potentially lead to the adoption of sub optimal public policies.

II.2. Disaggregate Demand Models

Given the obstacles to using aggregate data, economists developed disaggregate approaches to estimating freight transportation demand. Using data on individual decision-makers allows for a richer empirical specification and may provide for the ability to use a large number of observations (Small and Winston, 1998). A disaggregate model uses the characteristics of the individual decision-makers and a complete set of service attributes of different modes. Therefore, they may yield more accurate elasticity measures, based on specific characteristics of the options available to shippers. Further, disaggregate approaches do not require the assumption that decision-makers are identical (and/or that the results apply to a "representative" shipper, and are explicit about the source of random disturbances.

Disaggregate demand models can be classified into two categories: inventory and behavioral models (Winton, 1983). Inventory-based models analyze freight demand from the perspective of an inventory manager who deals with a number of production decisions, while the behavioral models deal with only one decision, the choice of mode (Abdelwahab and Sargious, 1992).

There are only a few articles that use the inventory-based modeling approach; most of these are theoretical in nature. On the other hand, there exists a plethora of literature that uses the behavioral approach and is empirical in nature. This literature covers many topics including the mode choice of shippers, households, individual passengers, and vacationers.

Inventory-Based Demand Models

Inventory-based models analyze freight transport demand from the perspective of an inventory manager. These models differ from the behavioral models in that they attempt to integrate the mode choice decision with other production decisions (Abdelwahab and Sargious, 1992).[8]

In their seminal paper, Baumol and Vinod (1970) develop the inventory-based demand model. They analyze the transport mode decision made by shippers, and the total demand for transportation services. They develop two approaches to the model, an abstract mode approach[9] and standard inventory theory.[10]

In explaining freight shipment decisions, the authors include the following considerations: shipping cost per unit, mean shipping time, variance of shipping time and carrying cost per unit of time while in transit. In order to determine how a shipper chooses between modes, the shipper's indifference curve is specified. The authors use inventory theory

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[8] Examples of literature containing inventory-based models are: Baumol and Vinod (1970), Das (1974), Roberts (1977), Constable and Whyback (1978), McFadden (1981), and Bevilacqua (1978). Abdelwahab and Sargious (1992) present a brief overview of this literature in their article.

[9] This is a technique that describes the type of carrier as a vector of values, which specify the attributes of that carrier offered to shippers.

[10] A mode is defined as the vector $m_i = (m_{i1}, \dots, m_{in})$ where the element m_{ij} is the value of the j-th variable (e.g., speed or reliability) characterizing mode i. Under this type of framework, slow and fast trains make up two different modes because the vectors characterizing the two modes differ with respect to the value of speed. These two modes would likely be considered equivalent in other studies because they are both rail modes.

to investigate the tradeoff between two attributes. They note that "if one can describe exactly how transit time affects the inventory level (safety stock) and, hence, carrying costs, one can proceed to determine the pertinent indifference relationship" (Baumol and Vinod, 1970, p. 416). The abstract mode approach was originally created to analyze the demand for passenger travel, but is extended by Baumol and Vinod to apply to many modes and commodities.

The authors develop three equations to produce the indifference curves. The first equation is a cost function derived under the assumption of perfect certainty, hence, making the safety stock (inventory level) equal to zero.[11] Although the safety stock is equal to zero, the authors use this as the base case in deriving the indifference curves from the cost functions.[12]

The next case introduces uncertainty to demand forecasts and delivery time and adds a term defining safety stock to the previous cost equation to examine the effect of uncertainty. The inclusion of this additional term makes it impossible to extract the indifference curves from the new equation.

Recognizing that firms maximize profit, Baumol and Vinod derive a total profit equation. From this equation, the optimal demand for transportation can be calculated using nonlinear estimation techniques. With a change in the original assumptions of the model the authors arrive at an equation that explicitly defines annual tonnage shipped, T:[13]

(Eq. II.2.1) $$\mathbf{T = (1/b)*[\Delta p - r - ut - ws/2 - wk - wk\,(s + t)^{1/2}\,]}$$

where **Δp** is the price difference between origin and destination, **r** is the shipping cost per unit of

[11] In the case of perfect certainty, transit time and final consumer demand for the product can be predicted with perfect foresight.

[12] This is achieved by setting the cost function C equal to a constant K.

[13] This is achieved by defining safety stock as being proportional to the total volume of shipments, T,

commodity, **u** is the in transit carrying cost per unit, **t** is the average time required to complete a shipment, **w** is the warehouse carrying cost per unit per year, **k** is a constant, **s** is the average time between shipments and **b** is the slope of the demand curve.

Baumol and Vinod note three contributions of their theoretical model. First, their approach displays increased analytical power. For example, their approach enables one to infer what would happen to demand given a change in any of the attributes. These are the results from estimating demands for attributes rather than demands for modes themselves. Second, their approach allows incomplete data to be used; these data would otherwise have to be used in discrete batches.[14] Third, this approach provides the ability to internally test the results and accuracy of the demand estimates.[15]

The authors name two shortcomings to their approach. First, their approach would not be applicable to situations attempting to examine anything more than mode choice. Second, in order to derive the explicit equation defining annual tonnage shipped, **T**, the authors had to alter a major assumption. The original definition of safety stock was used in the first equations while it was redefined for the sole purpose of explicitly defining **T**, the annual tonnage shipped.

Behavioral Demand Models

The core of the literature pertaining to behavioral models is based on the notion that the

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instead of to its square root, as it was previously defined.

[14] This applies to a case where data on individual commodities and modes is sparse or incomplete, and thus cannot be used to estimate a demand function. They treat all modes as variants of a single mode, displaying different values for attributes. Hence, all of the data for the different modes and commodities can be combined to create a larger, more useful, data set.

[15] Baumol and Vinod provide the following example to illustrate this advantage. With data relating to four different modes, one can use the information about three modes to forecast the demand for the fourth mode as though it was a carrier that did not exist yet. By comparing the predicted demand for the fourth mode with the known demand, one would be able to test the performance and accuracy of the estimation method.

decision-maker maximizes utility with respect to the choice of mode. Although a number of disaggregate demand analyses preceded that of McFadden (1973), this work laid the foundation from which many other behavioral models are built (Winston 1985).[16]

Random Utility Models: Discrete Choice

The approach McFadden (1973) presents in his paper is that of utility maximization, where the utility function includes a random component. In this random utility approach the decision-maker makes a discrete choice by choosing among **J** alternative modes. The choice of the mode from the **J** available alternatives is assumed to maximize the decision-maker's utility. The utility function for the individual decision-maker is specified as follows:

(Eq. II.2.2) $$\mathbf{U_i = V(\beta; X_i, S) + \varepsilon (X_i, S)}$$

with $\mathbf{i = 1, \ldots, J}$ and where $\mathbf{U_i}$ is the utility associated with transportation using mode $\mathbf{i}$. The utility function is comprised of an observed and an unobserved, or random, component. The observable part of the utility function is $\mathbf{V(\beta; X_i, S)}$, where the vector function **V** consists of a vector of unknown parameters, $\boldsymbol{\beta}$, a set of modal attributes, $\mathbf{X_i}$, and the socioeconomic characteristics of the decision-maker, **S**.[17] **V** is systematic utility, that is, the same functional form applies to all shippers. The random portion of the utility function is $\mathbf{\varepsilon(X_i, S)}$. This component of the utility reflects the unobserved tastes, preferences and characteristics of the individual decision-maker. Consequently, this term varies across decision makers.

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[16] Some of these early studies include Lisco (1967), Quarmby (1967), Domenrich et al. (1968), Lave (1969,70), Quant (1970), etc. See Winston (1985) for a more complete reference of early disaggregate work.

[17] The summary of McFadden (1973) relies, in part, on information provided in transportation demand surveys written by Winston (1985) and Small and Winston (1990). Both surveys contain excellent explanations and

According to the utility maximization assumption, the individual shipper chooses a particular mode **i** only if the utility realized from choosing mode **i** is greater than the utility realized from any other mode. Thus, the individual will choose mode **i** if $\mathbf{U_i > U_j}$ for all $\mathbf{i \neq j}$. In this model choices are predicted as probabilities, where the probability that the shipper chooses mode **i** is:

(Eq. II.2.3) $$\mathbf{P_i = Prob[U_i > U_j \text{ for all } i \neq j]}$$

Thus, the mode-choice probabilities depend, in part, on the random utility differences $(\boldsymbol{\varepsilon_i - \varepsilon_j})$, and their distribution (Small and Winston, 1998).

Using this framework, McFadden extends the mode-choice model to situations when the decision maker is confronted with more than two alternatives. He accomplishes this by assuming that the distribution of the random components follows the extreme value distribution.[18]

In a study by Daughety and Inaba (1978), the authors evaluate decisions confronting an elevator shipper that ships corn to various markets. The logit model is appropriate here because only one market and one mode are chosen to maximize the elevator's choice function (net-price or net-profit). It is assumed that the shipper is able to sell goods in various local markets, and that the market price is taken as given for the good and the transportation rates.

Different transportation modes are distinguished by their service attributes and by the costs induced by such attributes. These attributes include equipment availability, transit time and loading facilities. The varying level of reliability across modes introduces risk into the shipper's

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details regarding the random utility model framework presented by McFadden (1973).

decision regarding mode and destination. Since elevator operators highly value equipment availability, Daughety and Inaba construct a measure for the availability attribute. Measured as the expected delay, the transport availability for a small shipper was 7.8 days and $0.0042/per bushel, and for a large shipper 13.5 days and $0.0072/per bushel.[21] Availability costs for truck transportation are assumed to be zero since trucks are readily available for small and large shippers.

Three exogenous variables in the observable portion of the model are the price at the j-th market, the transport rate of shipping to the j-th market by mode m and the availability cost associated with shipping by the m-th mode. The data used in the study are from a week in October of the 1975 harvest season. These data include price, quantity, transportation rate, destination, mode and distribution of delay times. The average regional prices from the database are used as proxies for the actual prices at the markets considered. The average price of corn is equal to $2.663 per bushel in the River region and $2.605 per bushel in the Local region[23]. Transportation rates for alternatives not chosen are estimated from data on shipment sizes, rates paid and distance shipped. River and Local regions are designated as the markets, while truck and single-car rail are designated as the mode choices.

The results of the study are displayed in Table II.2.1. Two logit models are estimated: (1) a net-price model determined by prices, rates and per unit cost, and (2) a net-profit model, where the prices were multiplied by the shipment size. The net-price model predicts the correct choice

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[18] For a more complete discussion see McFadden (1973) and Small and Winston (1990).

[21] A small shipper is defined as one using truck or single car rail transport, while a large shipper is defined as one using truck, single or multi-car rail transport.

[23] The River market covered Midwest/Mideast destination points on the Missouri, Mississippi, Illinois and Ohio Rivers and Chicago. The Local market refers to all other Midwest/Mideast traffic.

90 percent of the time, while the net-profit model predicts the correct choice 82 percent of the time. However, the parameters for the price variables are not statistically significant. Daughety and Inaba attribute this to the negotiating of bid prices and quantities between buyers and sellers. The coefficients for the revenue variables are significant at 1 percent level. This phenomenon is also explained by the bid negotiations. In light of such findings, Daughety and Inaba base their analysis and demand estimation for the remainder of the paper on the net-profit model.

Table II.2.1

Net-Price and Net-Profit Logit Models

	River (Price)	Local (Price)	River (Truck)	Local (Truck)	River (Rail)	Local (Rail)	Availability
Net-price %: 90 LRI: .6865	2.626 (1.046)	3.176 (1.193)	-33.21 (-3.889)	-64.63 (-4.491)	-16.74 (-3.547)	-25.29 (-3.410)	-457.5 (-2.394)
Net-profit %: 82 LRI: .4028	.00141 (3.412)	.00131 (2.945)	-.009604 (-3.925)	-.01282 (-3.297)	-.004848 (-3.635)	-.001574 (-3.060)	-.06695 (-1.951)

Daughety and Inaba also estimate rate functions by regressing freight rates on shipment data. These rate functions are then used to estimate demand functions. The results of two alternative demand functions are displayed in Table II.2.2 for four alternatives: (1) truck to the river, (2) truck-local, (3) single-car to the river and (4) single-car-local. The authors urge caution in the use and interpretation of the demand estimates they produce, however, as they state that the high linearity reflected in the estimates is a result of the linear functions used to derive the demand curves. Daughety and Inaba improve the approach by using industry supply curves based on cost analysis and by increasing the number of observations.

Table II.2.2

Alternative Demand Functions

Alternative	t_n	Constant	R^2
1	$-7.0341*10^8$	$1.1477*10^8$	.99
2	$-5.4795*10^8$	$5.8201*10^7$	.98
3	$-1.3673*10^8$	$2.526*10^7$	.99
4	$-3.3604*10^8$	$1.1122*10^8$	.93

Winston (1981) develops a model of freight demand based on the random utility model and uses disaggregate data for a much broader set of markets. His econometric model answers the following question: "What are the critical determinants of mode choice in freight transportation and what policy guidelines do these results have to offer?" (Winston, 1981, p. 982). This article examines a distribution center and its role in mode-choice decisions.

Winston takes the final choice of mode as being the responsibility of the regional physical distribution manager of either the shipping or receiving firm. Thus, two cases are considered: The case where the receiving firm makes the mode choice, and hence, pays the transportation costs; and the case where the shipping firm makes mode choice, and pays the transportation costs.[24]

Winston formulates a shipper and receiver behavior in the context of McFadden's (1978)

[24]In the second case, where the shipper is making the choice of mode, it is assumed that the shipper does

random utility model. The formal theory of shipper behavior incorporates the Hicks-Zeuthen bargaining model. The formal theory of the receiver behavior, however, is developed in a Lancaster-type framework.[25] Different approaches are used because the modal attributes, such as speed, reliability, loss and damage, etc. may be more important to the receiver's utility as compared with the originator's utility. Winston note a set of problems confronted by each:

Case 1 (receiver makes the decision): Receiver maximizes expected utility with respect to the modal attributes of the i-th mode subject to a constraint on the quantity received.

Case 2 (shipper makes the decision): Shipper chooses the mode that maximizes the joint discounted value of expected utility of the receiver and him/herself.

An expected random utility model is derived for the case when the receiver is the decision maker and is then extended to include the case when the shipper is the decision maker. The random utility model for the k-th firm (shipping or receiving) is:

(Eq. II.2.4) $$\mathbf{EU_i^{\,k}(Z_i, S^k) = V(Z_i, S^k) + \varepsilon_i^k}$$

where the error term, $\boldsymbol{\varepsilon_i^k}$, contains unobserved variation of the firm's attitude toward risk and the expected value of unobserved modal, commodity and firm attributes. A multinomial probit model is chosen for estimation because, unlike the logit model, it allows for correlated error terms. In order to employ the single equation approach to estimating behavioral demand, Winston makes the assumption that shipment size and firm location are exogenous to the decision maker. Other variables include the value of the commodity, freight charges, mean and standard deviation of transit time, reliability and firm sales.

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not have monopoly power or that the shipper and the receiver represent the same firm.

Winston uses two different data sets in his estimation. To estimate the receiving firm model, he uses data containing perishable agriculture commodities only. These data are gathered at the receiving firms' cities and include information on origin-destination pairs for freight carried by rail and exempt-motor freight throughout 1975 and 1976.

The shipper's model is estimated using data containing a wide variety of commodities. This data set contains information on a large number of shipments made by rail, regulated motor freight and private carriers for 1976 and 1977.

Table II.2.3 features the results for this study. The parameter estimates and statistical significance vary greatly across the commodity groups. The freight charge and location coefficients are statistically significant for all the models. But the coefficient estimates for service quality variables differ in their statistical significance. The authors find that the model with independently distributed errors cannot be rejected for the commodity groups that displayed statistically insignificant service quality parameters.

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[25] The Lancaster approach to consumer behavior claims that consumers derive utility from attributes of a good, not the good itself.

Table II.2.3

Shipper's Model Estimates

Commodity Group	Mode Considered	Point Estimates (Stand. Errors)			All Alternatives (Days)		
		Shipment Size (10,000 lbs.)	Commodity value ($/pound)	Freight charges ($1000)	Mean Transit Time Rail	Mean Transit Time Exempt	Mean Transit Time Common
Unregulated Agriculture	Rail exempt motor freight	-0.959 (0.090) (motor freight)	0.268 (0.063) (motor freight)	-2.026 (0.276)	-0.992 (0.166)	-0.646 (0.257)	
Regulated Agriculture	Rail common private	5.36 (1.34) (rail)	34.7 (25.2) (rail)	-3.09 (.60)		-2.44 (.81)	
Textiles and Fabricated Textiles	Rail common private	16.7 (3.28) (rail)	-44.2 (7.9) (rail)	-.69 (.31)		.57 (.51)	
Chemicals	Rail common private	5.04 (1.32) (rail)	-.35 (1.46) (rail)	-13.8 (.93)		-1.9 (1.01)	
Leather, Rubber, and Plastic Products	Rail common private	1.68 (.9) (rail)	4.35 (3.5) (rail)	-3.29 (.6)		-.04 (.94)	
Stone, Clay, and Glass Products	Rail common private	11.38 (3.13) (rail)	-.73 (.197) (rail)	-4.10 (1.49)		2.74 (2.01)	
Primary and Fabricated Metals	Rail common private	4.15 (1.96) (rail)	-13.82 (2.99) (rail)	-6.99 (.995)		8.28 (1.89)	
Machinery inc. Electric Machinery	Rail common private	19.94 (1.51) (rail)	-10.125 (1.49) (rail)	-6.242 (1.73)	3.46 (1.48)	.697 (.696)	1.63 (.97)
Transportation Equipment	Rail common private	.006 (.016) (rail)	4.66 (2.14) (rail)	-3.52 (1.10)		-1.41 (1.08)	
Paper, Printing and Publishing	Rail private	1.98 (3.11) (rail)	8.69 (15.7) (rail)	-14.08 (7.06)		-1.76 (.60)	
Petroleum, Petroleum Products	Rail private	1.73 (.671) (rail)	3.76 (2.95) (rail)	-2.98 (1.08)		-3.54 (1.07)	
Lumber, Wood and Furniture	Rail private	2.39 (2.75) (rail)	6.51 (5.11) (rail)	-24.14 (10.4)		-4.32 (3.33)	

Commodity Group	Standard Deviation Transit Time (days)	Reliability (σ/χ)	Location (miles from rail siding) Rail	Sales ($ billion) Private	Covariance Specification
Unregulated Agriculture	-0.819 (0.229)	0.626 (0.193)			Independent
Regulated Agriculture	-12.7 (4.04)	11.5 (5.84)	-35.4 (14.0)	-0.17 (.13)	Dependent
Textiles and Fabricated Textiles	.14 (1.61)	7.9 (8.83)	-25.1 (5.09)	5.4 (1.3)	Independent
Chemicals	2.3 (2.53)	-10.5 (2.54)	-20.5 (3.7)	.865 (.22)	Dependent
Leather, Rubber, and Plastic Products	1.18 (2.94)	1.03 (5.17)	-18.2 (8.94)	.88 (.85)	Independent
Stone, Clay, and Glass Products	-13.3 (2.16)	32.4 (5.01)	-39.34 (13.8)	5.57 (1.51)	Dependent
Primary and Fabricated Metals	-8.94 (1.91)	6.89 (2.1)	-85.05 (8.66)	.09 (.2)	Dependent
Machinery inc. Electric Machinery	10.05 (8.97)	-19.12 (1.51)	-69.78 (11.9)	1.96 (1.09)	Dependent
Transportation Equipment	-.985 (2.90)	-1.53 (4.84)	-12.08 (3.81)	-.04 (.063)	Independent
Paper, Printing and Publishing	-4.21 (1.05)	.413 (1.33)	-15.23 (10.3)	-4.52 (4.62)	Independent
Petroleum, Petroleum Products	-1.05 (1.94)	9.23 (3.28)	-25.78 (13.15)	-.950 (.571)	Independent
Lumber, Wood and Furniture	2.81 (1.83)	-5.39 (4.78)	-9.59 (5.67)	-6.86 (6.28)	Independent

Table II.2.4 from Winston identifies the commodity groups with service quality parameters significantly different from zero at the five percent level. Winston finds that the commodities most sensitive to service quality are those containing perishable items or inputs to perishable items (Regulated Agriculture, Primary and Fabricated Metals, and Paper, Printing and Publishing). The non-perishable commodities without inventory needs are least sensitive to service quality variables (Textiles and Fabricated Textiles, Leather, Rubbers and Plastic Products, and Transport Equipment).

Table II.2.5

Service Quality Parameters Significantly Different from Zero at the Five Percent Level[a]

Zero	One	Two
Textiles and Fabricated Textiles	Chemicals	Regulated Agriculture
Leather, Rubber and Plastic Products	Stone, Clay and Glass Products	Primary and Fabricated Metals
Transport Equipment	Machinery, including Electrical Machinery	Paper, Printing and Publishing

[a]In order to avoid confounding structural and sample size effects, the table only includes commodity groups whose sample sizes were relatively similar.

Winston concludes his study by calculating the market elasticities of demand for various modal attributes using probit estimates of his model. These elasticities are provided and discussed in Section III. One of the shortcomings of Winston's study is the averaging out of seasonal effects. Thus, the author states that his approach failed "to completely control for the volume of a given firm's shipping activity over its normal production cycle" (Winston, 1981, p. 998), and that the future estimation should consider examining mode choice over a longer time horizon. He also stresses the advantages of the disaggregate behavioral demand model, such as richer econometric specification, more precise estimates of market elasticities, and the foundation in behavioral theory.

Random Utility Models: Joint Choice and Simultaneous Equations

Like the early aggregate models, the disaggregate discrete mode choice models came under scrutiny. Much of the scrutiny stemmed from the inability to account for the simultaneous decisions frequently made with the choice of mode. For example, Winston (1981) makes the assumption that both shipment size and location are exogenous to the choice of mode. In response, a new generation of transportation demand models have emerged that recognize the simultaneous decisions made with the choice of mode, such as shipment size and destination.

The basic discrete choice model is extended to allow for joint choices.[26] The early models define a joint choice by combining discrete choices; choice of mode is combined with choice of destination. McFadden (1978) developed the nested logit model that accounted for the preferences over a class of outcomes by allowing the random utilities to be correlated within groups, but not across groups (Small and Winston, 1998). Thus, the joint choice process is categorized by groups of possible outcomes, and the discrete choices are made simultaneously.

Mixed continuous/discrete choice models provide another way of analyzing joint choices. These models define a joint choice as a continuous choice made in conjunction with a discrete choice. This approach has recently been applied to estimating freight transport demand.

Inaba and Wallace (1989) implement a switching regression model or self-selectivity model, to estimate the demand for freight transportation. They address two issues: 1. The simultaneity between the mode choice and the shipment size decisions; and 2. the effects of spatial competition on the demand for freight transportation. The switching regression model is used to account for the possible endogeneity of the shipment size with respect to the mode choice.

Equations for shipment size and profit, conditional on the mode choice, are derived. The shipment size for a given mode and firm is defined as a function of distance between a supplier and the firm, the firm's storage capacity, and a *subset* of the mode-specific characteristics. The firm's profits are defined as a function of distance between a supplier and the firm, the firm's

[26]For a detailed discussion of joint choice literature see Small and Winston (1990).

storage capacity and the *entire* set of characteristics of mode-specific characteristics. The profit function determines the optimum mode choice and the optimum shipment size.

To control for correlated errors in the shipment size and profit equations, Inaba and Wallace use a two-stage method developed by Lee (1982) to estimate their model. In the first stage, a conditional logit model is used to produce the coefficient estimates for the distance and mode characteristics variables. In the second stage, these coefficients are used in the shipment size equation to form selectivity corrections, and the shipment size equation is estimated using weighted least squares. The conditional logit model and the shipment size model containing the selectivity correction are then combined to form the unconditional expected transportation demand for a given mode.

The authors use survey data of grain elevators with federal or state licenses in Idaho, Oregon, Montana and Washington for the year 1984. The survey included questions about capacity, loading facilities, service and handling charges, costs, loading times, service characteristics, destination prices for wheat, and shipment costs. The data collected are not only the costs and characteristics of the mode used, but also those of the alternative modes.

The estimated results indicate that higher service costs for a given mode lower the probability of the mode being chosen. The coefficient estimates of the dummy variables for unit trains and barge indicate that these modes are preferred if they are available. A test for misspecification bias reveals that there is simultaneity between shipment size and mode choice. The authors also estimate a set of demand elasticities. Table II.2.6 presents the unconditional average demand flows and average rate elasticities per contract destination. The demand functions are relatively rate inelastic due to the short-run nature of the mode decisions studied.

Table II.2.6

**Unconditional Average Demand Flows (Bushels)
and Average Rate Elasticities Per Contract Destinations**

Region	Destinations						
	Seattle	Portland	River	California	Great Falls	Ogden	Minneapolis
Montana							
Barge Flow	NF	NF	NF	NF	NF	NF	NF
Barge Elast.							
Truck Flow	2,236	2,277	4,311	1,463	4,698	4,728	2,310
Truck Elast.	-.733	-.615	-.346	-.690	-.445	-.603	-.459
Single Flow	1,470	1,572	3,085	1,042	2,718	3,847	1,027
Single Elast.	-.224	-.127	-.123	-.499	-.077	-.077	-.233
Mult. Flow	1,382	1,732	2,441	995	3,337	5,287	571
Mult. Elast.	-.275	-.103	-.180	-.05	-.08	-.06	-.823
Unit Flow	12,885	73,452	NF	NF	NF	NF	NF
Unit Elast.	-.087	-.045	NF	NF	NF	NF	NF
Truck/B Flow	NF	2,116	NF	NF	NF	NF	NF
Truck/B Elast.	-.148	NF	NF	NF	NF	NF	NF
Truck/M Flow	1,076	1,298	2,432	618	1,072	2,811	380
Truck/M Elast.	-.233	-.154	-.075	-.421	-.192	-.121	-.153
Eastern Washington							
Barge Flow	NF	57,294	NF	NF	NF	NF	NF
Barge Elast.	NF	-.007	NF	NF	NF	NF	NF
Truck Flow	839	1,287	2,173	694	NF	NF	NF
Truck Elast.	-.607	-.433	-.253	-.921	NF	NF	NF
Single Flow	669	862	1,678	516	NF	NF	NF
Single Elast.	-.912	-.243	-.048	-1.05	NF	NF	NF
Mult. Flow	598	908	1,281	547	NF	NF	NF
Mult. Elast.	-.985	-.242	-.179	-1.04	NF	NF	NF
Unit Flow	13,648	66,636	NF	NF	NF	NF	NF
Unit Elast.	-.069	-.043	NF	NF	NF	NF	NF
Truck/B Flow	NF	8,210	NF	NF	NF	NF	NF
Truck/B Elast.	NF	-.058	NF	NF	NF	NF	NF
Truck/M Flow	734	881	1,097	613	NF	NF	NF
Truck/M Elast.	-.599	-.283	-.101	-.897	NF	NF	NF

The authors identify three advantages of their study. First, their theoretical model demonstrates the conditions under which shipment size and mode choices are generated from the same optimization problem. Second, their model fills a gap between the spatial econometric models and the highly spatial but less behaviorally complete models. Third, the authors' research hypotheses are largely validated in the empirical results. Drawbacks of the model include omission of the farmer's reservation prices and distributional assumptions of the error terms (Inaba and Wallace, 1989, p. 624).

Abdelwahab and Sargious (1992) present an alternative approach to analyze the joint choices of mode and shipment size. The authors introduce a third equation to the general structure of the switching simultaneous equations model derived by Lee (1980) and used by Inaba and Wallace (1989). This third equation eliminates the problems associated with modeling two choices, one of which is discrete and the other continuous.

The first equation of the model specifies the unobserved index determining the mode choice. The second and third equations define shipment size for rail and truck modes as a function of exogenous variables. The exogenous variables include modal, commodity and market attributes. The data come from the Commodity Transportation Survey. The authors begin by estimating a reduced form probit model of the unobserved index of choice. The estimates from the probit model are then used in the two stage least squares estimation of the shipment size equations.

Table II.2.7 presents the results to the equation of mode choice. The estimated coefficients of the service variables in the mode-choice equation have the correct signs and are statistically significant. The results to this equation suggest that trucks are favored for transporting lighter and higher valued commodities.

Table II.2.7

ML Estimates of the Reduced Rail Truck/Rail Choice Equation

Variable	Parameter	ML Estimate	"t" statistic
CONSTANT	π_0	2.4795	18.4*
TON	π_1	-0.0100	-3.8*
DEN	π_2	-0.0030	-5.0*
VAL	π_3	0.1014	3.0*
LIQ	π_4	0.0462	0.5
GAS	π_5	-0.2916	-1.0
PART	π_6	-0.0584	-0.6
TMP	π_7	-0.2092	-1.2
SHK	π_8	-0.5912	-2.7*
RD2	π_9	0.4905	6.1*
RD4	π_{10}	0.2718	2.2*
TTIME	π_{11}	-1.6943	-17.0*
TCOST	π_{12}	-0.1183	-13.7*
TLD	π_{13}	-0.0149	-9.1*
RCOST	π_{14}	0.0160	20.4*
P^2		0.4086	
L(β)		-682.7	
% Truck		0.6324	
Mean Prob.		0.6306	
N. Obs.		1586	

* Significant at the 5% level.

Table II.2.8 presents the results from the equations for the shipment size of rail and truck service. All of the estimated coefficients in the shipment size equations are significant. This is not surprising because the authors ran a series of regressions using all or a combination of the 27 exogenous variables and then chose the one with the best overall fit. Denser, gaseous, and temperature controlled commodities tend to be moved in larger quantities using trucks. Denser and gaseous commodities are moved in larger quantities using rail as well. Traffic density is positively related with shipment sizes of trucks and negatively with shipment sizes of rail transportation. The results show that shipment size varies significantly across different geographical regions.[27] The authors test and find evidence of interdependence between the decisions of mode and shipment size.

Table II.2.8

ML Estimates of the Truck Shipment Size Equation, ST

Variable	Parameter	ML Estimate	"t"-statistic
CONSTANT	α_0	13.9352	45.9*
TON	α_1	0.0336	5.3*
DEN	α_2	0.0084	6.7*
GAS	α_3	2.3496	3.3*
PART	α_4	0.5734	3.4*
TMP	α_5	1.0467	3.6*
SHK	α_6	-1.0597	-2.2*
RD1	α_7	-0.6262	-3.8*
RD2	α_8	-4.4183	-19.7*
RD4	α_9	-4.8770	-14.4*
TTIME	α_{10}	16.6232	76.5*
TCOST	α_{11}	0.0149	6.2*
TLD	α_{12}	0.2630	10.0*
RCOST	α_{13}	-0.0935	-46.8
R^2		0.8249	
$L(\beta)$		-2293.7	
σ_1		2.3827	
$P_{1\varepsilon}$		-0.1936 (t=-1.65**)	
N. Obs.		1003	

* Significant at 5% level. **Significant at 10% level.

[27]The authors compare shipment sizes in two regions using the Interstate Commerce Committee classification of the regions; shipment sizes in Official, Southern, and Southwestern Territories are compared with those in Mountain Pacific Territory.

ML Estimates of the Rail Shipment Size Equation, SR

CONSTANT	β_0	83.2765	6.1*
TON	β_1	0.2594	10.7*
DEN	β_2	0.0894	9.8*
VAL	β_3	-1.7730	-3.4*
LIQ	β_4	4.8161	3.3*
GAS	β_5	29.8602	9.0*
PART	β_6	5.9057	4.6*
RD2	β_7	-11.7037	-11.2*
RD4	β_8	-9.4014	-6.9*
RTIME	β_9	9.8227	10.7*
TCOST	β_{10}	0.1601	10.4*
TLD	β_{11}	2.2626	5.6*
TREL	β_{12}	-51.7894	-6.7*
RLD	β_{13}	-0.4760	-4.6*
RCOST	β_{14}	-0.2703	-33.0*
R^2		0.7238	
$L(\beta)$		-2356.3	
σ_2		13.7720	
$P_{2\varepsilon}$		0.4868 (t=2.66*)	
N. Obs.		583	

* Significant at 5% level.

Abdelwahab (1998) extends the study of Abdelwahab and Sargious (1992) to include estimates of elasticities of mode choice probabilities and market elasticities of demand. The author reports both aggregate and disaggregate elasticities. The disaggregate elasticity is defined as the change in a shipper's probability of choosing a mode in response to a change in the values of the mode's attributes. The aggregate elasticity is a weighted average of these disaggregate elasticity measurements with the weights being the mode choice probabilities. Abdelwahab uses the coefficient estimates from the joint choice model to generate values for the market elasticities of demand. Four different price elasticities are calculated, one for each market segment, as defined by Abdelwahab. The elasticity estimates derived in this study are discussed in greater detail in Section III.

Summary of Random Utility Models: Joint Choice and Simultaneous Equations

Many advantages stem from extending the basic discrete choice model to the simultaneous equation model for estimating joint choices of mode and shipment size. The simultaneous equation models are used to analyze spatial policy issues, identify interaction between mode and shipment decisions, examine modal choice behavior and generate various elasticity estimates. However, the data requirements are extensive for estimating such a model, and the inability to obtain the required data may limit the explanatory power of this model. Also, a key assumption of the simultaneous equation model is the independence of the error terms across alternative modes, and a violation of this assumption would likely decrease the validity of the estimated results.

Shortcomings of Disaggregate Demand Models

Although disaggregate models are an improvement over the aggregate models, there are deficiencies. First, some of the models are very difficult to estimate if more than two alternatives (for example truck, rail and barge) are allowed. Second, the data required for the estimation of disaggregate models is usually difficult to obtain. In addition to detailed information regarding mode and shipment characteristics, shipper attributes are essential and can be difficult to obtain.

III. ELASTICITY ESTIMATES

In this section, we provide a more detailed discussion of the elasticity estimates derived in the studies discussed in Section II. The discussion centers on differences in estimates, functional forms, previous surveys, and our own comparisons of elasticities from different approaches and studies.

III.1. Functional Forms and Elasticity Estimates

One set of studies focuses on how the specification of functional form affects the estimated values of elasticities. Oum (1989) explores how changes in the specification of the model affect the elasticity estimates. He compares elasticity estimates for models that use four different functional forms: (1) Linear demand model; (2) Log-linear demand model; (3) Logit model; and (4) Translog demand model. He finds that changes in the estimated elasticities are a direct result of changes in the functional form of the model.

Oum first estimates a demand model for aggregate freight using the four different functional forms. Then, he compares the estimates obtained from each model and performs likelihood ratio tests for model selection. Oum finds that the Translog demand system is the best model for aggregate freight.

He then compares demand elasticities evaluated at mean values of the variables generated by the four models described above and a model using the Box-Cox specification. These elasticities are presented in Table III.1.1. The author points to three notable findings. First, the cross-price elasticities from the logit model are negative; a counterintuitive result. Second, the own-price and own-quality elasticity estimates from both the Box-Cox and Log-linear forms are higher than expected, while the Translog and Linear forms generate demand elasticities that are closer to the expected value. Third, the author suggests that the Translog model is not only robust but produces the most favorable elasticity estimates.

Oum repeats the process described above using a subset of the original data. These data include only one commodity, fruits, vegetables and other edible foods. The results are similar to those obtained from the aggregated commodity study and points to robustness of results. That is, the Translog model produced the most reasonable results (Table III.1.1).

Table III.1.1

Elasticity of Demand for Freight for all Commodities, Canada 1979

Elasticities	Model Type				
	Translog	Log-linear	Linear	Box-Cox	Logit
Elasticity of rail-truck substitution	1.19				
Own price elasticity					
-rail	-0.598	-1.517	-0.638	-1.384	-0.830
-truck	-0.692	-1.341	-0.048	-1.140	-0.928
Cross price elasticity					
-rail wrt truck price	0.498		0.059		-0.175
-truck wrt rail price	0.592	0.453	0.838	0.403	-0.616

Source Oum (1989, table 9, p. 181)

Table III.1.2

Elasticities for Commodity 14 (Fruits, Vegetables and Other Edible Foods)
(Evaluated at Means of Variables: t-statistics in Parentheses)

Elasticities	Translog	Log-linear	Linear	Box-Cox	Logit
SRH	1.147 (16.3)				
ERR	-0.688 (16.0)				
EHH	-0.459 (12.7)				
FRR	-0.796 (18.9)	-0.795 (2.8)	-0.391	-0.795	-0.484
FRH	0.495 (45.0)				-0.466
FHH	-0.652 (18.6)	-1.542 (9.0)	-0.318	-1.248	-0.970
FHR	0.351 (39.0)				-0.262
ERR^1	15.914 (2.1)				
ERH^1	-2.285 (6.0)				
EHH^1	1.523 (2.3)				
HER^1	-10.607 (5.9)				
FRR^1	18.413 (2.3)	26.559 (2.3)		26.561	2.52*
FRH^1	-1.644 (5.8)	-8.795 (1.9)		-8.776	-4.15*
FHH^1	2.166 (2.8)	3.892 (1.8)		2.808	2.34*
FHR^1	-8.119 (6.2)				-1.41*
ERR^2	44.589 (1.9)				
ERH^2	-4.127 (6.4)				
EHH^2	2.751 (2.4)				
HER^2	-29.720 (5.1)				
FRR^2	51.592 (2.0)	243.388 (2.2)		243.41	
FRH^2	-2.969 (6.2)				
FHH^2	3.911 (3.0)		-30.269		
FHR^2	-22.750 (5.2)	-48.563 (5.4)		-40.324	

* Since the modal speed variables are not statistically significant in the total volume (rail and truck combined) equation, these ordinary demand elasticities for speed variables are in fact the same as the share elasticities.

Westbrook and Buckley (1990) specify a cost function with transportation demands through Shepherd's lemma. While they focus on determining a specification that satisfies regularity conditions, they also analyze how the alternative specifications of the cost function and transformed data affect elasticity estimates. The three functional forms reviewed in this study are Translog (TL), CES-Translog (CESTL), and the Barnett Translog (BTL). This study examines the fruit and vegetable commodity class as well.

Table III.1.3 provides the substitution elasticities and the cross- and own-price elasticities for rail and truck modes. The elasticities generated by the TL and BTL specifications are consistent with each other but quite different from those generated by CESTL. However, none of the specifications meet regularity conditions, and the authors proceed to find technologies that do.

Table III.1.3

Elasticities of Substitution and Demand for Rail and Truck Transportation Between Chicago and New York

Functional Form	Destination	Subs. Elast.	Own-price demand elast.		Cross-price demand elast.	
		Rail, Truck	Rail	Truck	Rail, Truck	Truck, Rail
TL	Chicago	5.43	-0.36	-0.41	0.32	0.45
	New York	2.70	-0.55	-0.53	0.22	0.42
CESTL	Chicago	1.55	-0.10	-0.12	0.09	0.10
	New York	0.55	-0.06	-0.11	0.04	0.09
BTL	Chicago	5.61	-0.39	-0.46	0.28	0.43
	New York	2.44	-0.09	-0.59	0.18	0.41

Source Westbrook & Buckley (1990, table 2, p. 627)

Substitution Elasticities and Demand Elasticities for the minimum Concavity Violation Cases

	Destination	σ_{12}	(s.e.)	ε_{11}	ε_{22}	ε_{12}	ε_{21}
TL	CHI	5.55	(0.53)	-0.84	-0.90	0.30	0.44
	NY	2.36	(0.16)	-0.80	-0.89	0.15	0.38
BTL	CHI	6.23	(0.57)	-1.10	-1.80	0.30	0.41
	NY	2.24	(0.13)	-0.07	-1.30	0.14	0.38

Westbrook and Buckley proceed by using *prior affine transformation* on BTL and TL to improve the concavity and hence minimize the number of concavity violations. The estimated elasticities of the transformed TL and BTL models are also provided in Table III.1.3. Although the estimates for the elasticities of substitution do not change much from those disclosed earlier, the authors find that the standard errors for the estimates decrease dramatically. Also, evidence of strong competition between rail and truck emerges as the estimates for the own-price elasticities of demand increase from those previously observed.

III.2. Surveys of Elasticity Estimates

There are a variety of survey articles in the literature. Some of these surveys and the studies involve comparisons of the estimates reported in different studies with different data sets, approaches, etc. Goodwin (1992) provides a thorough review of travel demand elasticities. In his paper, Goodwin surveys recent travel demand studies and provides a discussion of the relevance to policymaking. Goodwin believes that policymakers should be aware of how sensitive travel demand is to changes in travel prices. This review arrives at the intuitive conclusion that long-term elasticities are higher than short-term elasticities and suggests a dynamic component to travel demand responses and the effects of price changes over time.

Perhaps more relevant to freight transportation demand is the survey of Oum, Waters, and Yong (1992). This survey provides a detailed summary of the own-price elasticity studies. The literature analyzed by Oum et al. covers both passenger and freight demand and includes a wide range of modal alternatives. They first describe the various demand elasticity measures and review different demand models. Table III.2.1 shows the demand elasticity estimates of rail, truck and airfreight for various commodities and functional forms. They, as one might expect, find that elasticities range widely across both commodities and functional forms.

Table III.2.1

Elasticities of Demand for Freight Transport

Mode	Range surveyed	Most likely range	# of studies
Rail			
Aggregate commodities	-1.52 to –0.60 (-1.79 to –0.09)	-1.20 to –0.40	4
Assembled automobiles	-1.08 to –0.65	-1.10 to –0.70	2
Chemicals	-2.25 to –0.39 (-0.66)	-0.70 to –0.40	3
Coal	-1.04 to –0.02	-0.40 to –0.10	2
Corn, wheat, etc.	-1.18 to –0.52	-1.20 to –0.50	3
Fertilizer	-1.04 to –0.02	-1.00 to 0.10	1
Foods	-2.58 to –0.02 (-1.36)	-1.00 to –0.30	9
Lumber, pulp, paper, etc.	-1.97 to –0.05 (-0.87 to –0.76)	-0.70 to –0.10	7
Machinery	-3.55 to –0.61	-2.30 to –0.60	3
Paper, plastic and rubber products	-1.85 to –0.17	-1.00 to –0.20	4
Primary metals and metallic products	-2.54 to –0.02 (-1.57)	-2.20 to –1.00	5
Refined petroleum products	-0.99 to –0.53	-1.00 to –0.50	3
Stone, clay and glass products	-1.62 to –0.82 (-0.69)	-1.70 to –0.80	4
Truck			
Aggregate commodities	-1.34 to –0.05	-1.10 to –0.70	1
Assembled automobiles	-0.67 to –0.52	-0.70 to -0.50	1
Chemicals	-2.31 to –0.98	-1.90 to –1.00	2
Corn, wheat, etc.	-0.99 to –0.73	-1.00 to –0.70	2
Foods	-1.54 to –0.32	-1.30 to –0.50	3
Lumber, wood, etc.	-1.55 to –0.14	-0.60 to –0.10	3
Machinery	-1.23 to –0.04	-1.20 to –0.10	3
Primary metals and metallic products	-1.36 to –0.18	-1.10 to –0.30	3
Paper, plastic and rubber products	-2.97 to –1.05	-3.00 to –1.10	2
Refined petroleum products	-0.66 to –0.52	-0.70 to –0.50	3
Stone, clay and glass products	-2.17 to –1.03	-2.20 to –1.00	2
Textiles	-0.77 to –0.43	-0.80 to –0.40	1
Air			
Aggregate commodities	-1.60 to –0.82	-1.60 to –0.80	3

III.3. Our Comparison of the Price Elasticity Estimates

We constructed Table III.3.1 to allow comparisons between elasticity estimates from the literature reviewed in this paper. Table III.3.1 contains the own-price elasticity estimates for rail and truck modes and the cross-price elasticities for rail and truck. The estimates are from the following studies: Oum (1979), Friedlaender and Spady (1980), Winston (1981) and Abdelwahab (1998)[28]. Table III.3.1 also presents the characteristics of these studies. Elasticity estimates are presented for seven commodity groups: Food Products, Lumber/Wood Products, Chemicals, Primary and Fabricated Metal Products, Rubber & Plastic Products, Stone, Clay & Glass Products, and Electrical Machinery.

[28] Please note that the elasticity estimates reported by Winston (1981) are mode choice elasticities. The elasticities from Friedlaender and Spady (1980) are calculated for both the 'all region' and the 'Interstate Commerce Committee official region'. Also, the estimates from Abdelwahab (1998) are for the 'Interstate Commerce Committee official region' and the estimates from Oum (1979) for Canada.

Table III.3.1

Elasticity Estimates According to Author

Author	**Oum**	**Friedlander & Spady**		**Winston**		**Abdelwahab**
Model	Aggregate translog function	Aggregate translog function		Multinomial probit mode choice		Simultaneous equations
Data Type	Aggregate	Aggregate		Disaggregate		Disaggregate
Data Year	1970	1972		1975-1977		-
Market	Canada	All regions	ICC officia l	USA		ICC official regions
Type of Elasticity	**Commodity Groups Used for the Elasticity Estimation**					
	Fruits and Vegetables	**Food Products**		**Unreg. Agriculture**	**Reg. Agriculture**	**Food Products**
Cross-price (rail-truck)	-1.006	-.023	-.033	-	-	1.4888
Cross-price (truck-rail)	-.4522	.004	-.002	-	-	1.2612
Own-price (rail)	-1.037	-2.583	-2.680	-1.11	-.29	-1.499
Own-price (truck)	-.5212	-1.001	-1.010	-.99	-.27/-.32	-1.1963
Lumber, Wood, and Wood Products						
Cross-price (rail-truck)	-.5324	-.050	-.672	-		1.293
Cross-price (truck-rail)	-.5116	-.129	-.186	-		1.1125
Own-price (rail)	-.5814	-1.971	-2.106	-.08		-1.2816
Own-price (truck)	-.5626	-1.547	-1.719	-.14		-1.0591
Chemicals						
Cross-price (rail-truck)	-.6282	-		-		1.0421
Cross-price (truck-rail)	-.942	-		-		1.0786
Own-price	-.6882	-		-2.25		-1.0534

(rail)						
Own-price (truck)	-.982	-		-2.31	-1.87	-.927
Primary and Fabricated Metal Products						
Cross-price (rail-truck)	-1.176	-.059	-.545	-		.9042
Cross-price (truck-rail)	-.3318	-.099	-.164	-		.9326
Own-price (rail)	-1.198	-2.164	-8.656	-.019		-.9084
Own-price (truck)	-.4098	-1.364	-1.581	-.18	-.28	-.7972
Rubber and Plastic Products						
Cross-price (rail-truck)	-	.007	-.009	-		1.2592
Cross-price (truck-rail)	-	.003	-.004	-		1.2812
Own-price (rail)	-	-1.847	-1.897	-1.03		-1.2348
Own-price (truck)	-	-1.054	-1.083	-2.01	-2.97	-1.1358
Stone, Clay, and Glass Products						
Cross-price (rail-truck)	-	.025	.008	-		.9525
Cross-price (truck-rail)	-	.016	.005	-		.9818
Own-price (rail)	-	-1.681	-1.757	-.82		-.9558
Own-price (truck)	-	-1.031	-1.061	-2.04	-2.17	-.7494
Electrical Machinery						
Cross-price (rail-truck)	-	-.151	-.177	-		1.1672
Cross-price (truck-rail)	-	-.061	-.089	-		1.1991
Own-price (rail)	-	-3.547	-3.816	-.61		-1.1644
Own-price (truck)	-	-1.230	-1.312	-.78	-.04	-1.1938

As in previous surveys, this table shows there is substantial variation in elasticity estimates across commodities and between studies. The variation in elasticities over commodity groups and estimation methods is intuitive. Demand for transportation should not respond to changes in prices identically for all commodities. Similarly, one would not expect the responsiveness to price changes to be the same for all firms shipping the commodity, as the size, location, and characteristics of the firms vary. Different studies analyze behavior in different markets. Markets compared here range from Canada, to the entire US, to regions within the US, hence the variations in elasticities.

A closer look at Table III.3.1 yields other important information. The own-price elasticity estimates for rail service in Table III.3.1 vary from -0.019 (Winston, Fabricated Metal) to -8.656 (Friedlaender and Spady, Fabricated Metal). However, the majority of the estimates exceed unity in absolute value, and all of the estimates display a negative sign. This is an indication of rail service being elastic with respect to its own price. Food products, metals, and electric machinery are particularly elastic. For every commodity, the absolute value of the own-price elasticity estimates for rail derived by Friedlaender and Spady (1980) exceed estimates derived by the other studies.

For nearly all commodities and models, the absolute value of the own-price elasticities for truck service, also presented in Table III.3.1, are lower than those reported for rail. According to expectations, these estimates display negative signs. The own-price elasticities for truck vary from -0.04 to -2.97. This interval is a lot smaller than it for rail service. In fact, the majority of the own-price elasticity estimates for truck service are relatively close to unity. This indicates that the demand for truck service is less sensitive than the demand for rail service to own-price changes. The own-price elasticity estimates for truck from Abdelwahab (1998), for example, vary only slightly across commodities, staying between -0.7494 and -1.1938.

The cross-price elasticities in the table range between -0.674 and 1.489. The aggregate studies of Oum, and Friedlaender and Spady produce generally negative cross-price elasticities with low absolute values. These negative values suggest that shippers view the two modes as complements, while the low elasticity values suggest the demand for rail and truck service to be independent. Abdelwahab, using disaggregate data, produces elasticities which are not only positive but also much higher than those estimated by the aggregate studies. Abdelwahab's results, then, suggest that rail and truck service are substitutes.

Friedlaender and Spady justify their counterintuitive results by discrepancies in their data. Namely, most of the truck service in their data is associated with small shipment sizes, while rail service is associated with large shipment sizes. An alternative explanation may be the regulation of the rail industry.

Overall, aggregate and disaggregate models tend to produce noticeably different elasticity estimates. Another factor in explaining the differences in estimated values may be the time period under study. All studies except for Abdelwahab's use data from a time period in which rail rates were regulated; Abdelwahab uses data that are post-deregulation. Hence, variations in policy measures and regulation of transportation industries may influence the elasticity estimates.

IV. CONCLUSION

IV.1. Possibilities for Improving Future Research

As suggested by Oum et al. (1992), there are many aspects of the previously described studies that can be improved or extended in future research. First, previous studies ignore the presence of competition between modes and, hence, the own price elasticity estimates may be understated (Oum et al., 1992). Second, as is discussed in section III.3, the type of data used has an effect on the values of the elasticity estimates. Using disaggregate data is likely be more precise in estimating price elasticity of demand.

As suggested by this and other studies, there is a need to develop the relationship between short and long run estimation. As noted by Oum et al., even though demand becomes more elastic in the long run due to the ability to adjust to price changes, there is a need for "more carefully structured long-run studies" (Oum et al., 1992, p. 36). This could be achieved by including variables for choice of location and asset ownership, which reflect long-run decisions and affect elasticity estimates.

Oum et al. also urge researchers to carefully consider the underlying reasons in specifying a functional form for their estimation. As demonstrated in Section III, alternative specifications and functional forms may affect estimation results. It is also suggested that great care be taken in identifying possible interactions between demand and supply side variables in the analysis.

IV.2. Estimating Inland Waterway Transportation Demand the Improved Way

The improvements suggested in the previous section may also benefit studies of barge transportation demand. First, note that only a few studies attempt to estimate the demand for inland waterway transportation. Most freight transportation literature concentrates on rail and truck service, while failing to include barge service as a competing transportation mode.

In structuring a data set to estimate the demand for inland waterway transportation, it is helpful to consider the suggested improvements in Section IV.1. First, the prices and service quality attributes of modes competing with barge service ought to be included. This allows for competition between modes to have effects on the price elasticity estimates that would otherwise be distorted.

Second, researchers should consider carefully the use disaggregate data; these data should capture attributes of both the shipper and the shipment. Potential attributes of the shipper could include location, the stated preferences of carrier, destination, route choice, alternative modes, and the revealed preferences of carrier, route, or alternative locations or modes. Attributes of the shipment could include size, weight, destination and frequency as well as, of course, rates.

Third, a study of the barge transportation demand should incorporate the spatial nature of the transportation modes and the commodities. In doing this, the researcher may be able to decipher the sensitivity of demand with respect to the distance from competing modes.

VI.3. Final Remarks

The purpose of this paper is to review the freight transportation demand literature. We provide a summary of the methodology and the main results of aggregate and disaggregate demand studies. We follow the development of the empirical work through time. The comparison of elasticity estimates provides an illustration of how results may differ due to varying methodologies. We summarize the areas for improvement in estimating transportation demand suggested by Oum et al. (1992). Using these suggestions, we provide a guideline to estimating the inland waterway transportation demand. Although the suggested improvements provide only a general overview of the necessary components for a tractable analysis, they can be coupled with the existing methods of analyzing inland waterway transportation demand.

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- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
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September 1, 2005

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SPATIAL COMPETITION, SUPPLY AND TRANSPORTATION DEMAND

A Study of Elevator Competition and Waterway Demands with Geographically Varying Elasticities and Spatial Autocorrelation

US Army Corps of Engineers®

IWR Report 05-NETS-R-09

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Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

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The NETS program was overseen by Mr. Robert Pietrowsky, Director of the Institute for Water Resources.

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SPATIAL COMPETITION, SUPPLY AND TRANSPORTATION DEMAND

A Study of Elevator Competition and Waterway Demands with Geographically Varying Elasticities

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Spatial Competition, Supply and Transportation Demand

A Study of
Elevator Competition and Waterway Demands
with
Geographically Varying Elasticities and Spatial Autocorrelation†

by

Kevin E. Henrickson*

September 2005

Abstract

In this study, I develop and estimate a model of spatial competition between grain elevators. Grain elevators compete over space for products, which they in turn supply to the market and form the demand for transportation. I model these supply and corresponding transportation demands as as a function of prices, transportation rates and a variety of control variables. These control variables capture the spatial environment from which decisions are made. Further, elevators operate in different geographic areas with differing market and demand alternatives which imply structural breaks across regions. A variety of models designed to capture geographic differences in the elasticity parameter are employed to uncover structural breaks in the data along the geography of the network. Further, these elevators compete with each other spatially, with the result that their errors may be spatially correlated. To examine this possibility, I estimate a spatial autocorrelation model for the potential spatial clustering of errors. The results suggest that demand elasticities vary across the spatial environment, and that the presence of competitors can and does have a sizable impact on the structure of demand. These results are of central importance to policy-makers as they call into question the assumptions made by models currently in use for measuring the benefits of inland waterway improvements, and yet, provide estimates that are easily adapted to the models used to measure these benefits.

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1. Introduction

Economists have long recognized the importance of space in modeling economic relationships.[1] Most of this work has been theoretical in nature, and until recently, there is very little empirical modeling of these relationships.[2] In this study, I develop an empirically tractable model of spatial competition between grain elevators located on the inland waterway system, and their resulting barge transportation demand. The inland waterway system, on which these elevators are located, is of critical importance to the U.S. economy as it provides access to export/import markets from the interior of the country. However, much of the infrastructure of the inland waterway system is antiquated and in need of updating, a job which falls to the U.S. Army Corps of Engineers (ACE). In conducting benefit-cost analyses of proposed waterway improvements, ACE has used a suite of models whose foundations and assumptions have been evaluated and criticized by the National Research Council (NRC) of the National Academy of Sciences (NRC, 2001).

The model developed in this study, grounded in spatial competition, both fits directly into current ACE planning models, and overcomes many of the shortcomings identified by the NRC and others. I empirically apply this model to interview data collected by the Tennessee Valley Authority (TVA). In so doing, I use multiple techniques to examine the geographic pattern of barge demands using a variety of control variables which include measures of the spatial environment over which decisions are

[1] Two of the most common topics in the spatial economics literature are the size and shape of firms' market areas (e.g. Clark and Clark (1912), Fetter (1924), Lösch (1954), Mills and Lav (1964), and Eaton and Lipsey (1976)) and spatial pricing/competition (e.g. Hotelling (1929), Lerner and Singer (1937), Smithies (1941), D'Aspremont, Gabszewicz and Thisse (1979), Fujita and Thisse (1986), and Anderson, de Palma and Thisse (1989)).
[2] See Inaba and Wallace (1989) as an example of both a theoretical model, and empirical examination of transportation demand over space.

made. The results suggest that barge demand elasticities vary geographically, and are relatively elastic. Further, since grain elevators compete spatially for their products, and since their decisions are made in a highly competitive market, I estimate a spatial autocorrelation model as a robustness check for the potential spatial clustering of errors.

There are a number of transportation demand studies. In these studies there is a wide range of how the models are formulated and estimated.[3] There are two general classes delineated along aggregate and disaggregate dimensions. Aggregate demand models reflect aggregations of shipments. The aggregation can be over shippers, commodities, or shipments of particular shippers of a given commodity. Disaggregate demand modeling reflect examinations of individual shipments and the associated mode and/or market decisions from a set of alternatives. Baumol and Vinod (1970) estimate an inventory based model where the choice of mode is integrated with other production decisions. Also using individual shipment data, McFadden (1973), Daughety and Inaba (1973) and Winston (1981), Inaba and Wallace (1989), Abdelwahab and Sargious (1992) and Abdelwahab (1998) estimate transportation demand using random utility methodology.

[3] Within this literature many different forms of transportation demand have been analyzed for the various modes. For automobile usage, Mannering and Winston (1985), Hensher, Milthorpe and Smith (1990) among others find that demand is relatively inelastic. Similar results are found for urban transit demand (e.g. De Rus (1990)). Studies on the transportation demand for air passenger travel find a wide range of elasticity estimates. The literature on air passenger travel also finds evidence that the demand elasticity varies for the different fare classes (e.g. Oum, Gillen and Noble (1986) and Straszheim (1978)). Still other studies use discrete choice models to estimate travel demand elaticities (e.g. McFadden (1974)). Of more relevance for the topic at hand are the studies examining the demand for freight transportation, either rail (e.g. Boyer (1977), Wilson, Wilson and Koo (1988) and Winston (1981)) or truck (e.g. Friedlaender and Spady (1980), Wilson, Wilson and Koo (1988) and Winston (1981)). For a more complete treatment of transportation demand studies, see Oum et al. (1992).

Until recently, there have been relatively few studies of transportation demand that include barge transportation.[4] The controversy surrounding the NRC, however, has spurned considerable activity in the area. For example, a recent study by Train and Wilson (2005a) uses both revealed and stated preference data to analyze both mode and origin-destination changes as a result of a change in the barge rate. Using this framework they estimate barge demand elasticities between -.7 and -1.4, results similar to those found in this study.[5]

The present study adds to this literature by estimating a shipper disaggregated model of barge transportation demand, which is used to estimate the elasticity of barge transportation demand for elevators located along the Upper Mississippi and Illinois rivers shipping grain products, paying specific attention to the spatial nature of transportation demand.[6] In particular, I employ both rolling and locally weighted regression techniques as well as interaction terms and endogenous switch points to examine patterns in barge demand elasticity across a geographic space. The results of these methodological approaches indicate that barge demand elasticity varies geographically across the river with elasticity estimates ranging from -1.350 and -1.987. As a robustness check, a spatial autocorrelation model is estimated to examine the

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[4] With the most notable exception being Inaba and Wallace (1989) which uses self selectivity models to estimate transportation demand, including barge transportation demand, over geographic space.

[5] Other recent studies of barge demand elasticity include: Sitchinava, Wilson and Burton (2005) who use stated preference responses to study barge transportation demand on the Ohio river, finding that demands are elastic, but vary greatly across commodities and shippers; Train and Wilson (2005b) who use stated and revealed choice data on shippers in the Pacific Northwest, find that barge demand in this region is relatively inelastic and that the distance to the waterway is a significant factor in the decision to use the waterway; Dager, Bray, Murphree and Leibrock (2005) find relatively inelastic barge demand for corn shipments on both the Illinois and Mississippi rivers; and Yu and Fuller (2003) find relatively inelastic, though often insignificant, elasticity estimates for the Illinois and Mississippi waterways.

[6] Note that the focus of this study is on grain products as they are the most common commodity being shipped on the Upper Mississippi and Illinois rivers, with corn being the dominant commodity within the group. Also worth noting is that, by incorporating the spatial nature of transportation demand, this study addresses one of the NRC's other criticisms of the current ACE planning models (NRC, 2004).

possibility of geographically clustered error terms; however, tests for the appropriateness of this model indicate that the error terms of elevators are not spatially autocorrelated, which implies that the regional competition variables included in the model specification capture the local competitive environment of grain elevators located on the Upper Mississippi and Illinois Rivers.

The elasticity results found in this study directly call into questions the assumptions made by current planning models used by ACE, while also providing a contribution to the spatial modeling of demand models. The ACE models, used to calculate the estimated benefits of inland waterway improvements, have recently been the source of both controversy and criticism (NRC, 2004). Specifically, these models either assume that barge demand is perfectly inelastic or that demand is less than perfectly inelastic, but that this elasticity can be specified by the user rather than being empirically estimated. This study indicates that the assumption of perfectly inelastic demand in these models is at best questionable, and additionally, provides a methodology which fits directly into the current ACE planning models, and addresses many of the concerts expressed by the NRC.

The remained of this study is divided into 5 sections. Section 2 develops a theoretical model of spatial competition between grain elevators located along the waterway system. Section 3 outlines numerous empirical strategies of estimating the demand for barge transportation stemming from the theoretical model developed in Section 2. Section 4, outlines the data and variables used for the analysis. Section 5 presents the results of the various empirical specifications, while in Section 6 provides concluding comments.

2. Theoretical Model

This study is primarily focused on the transport of agricultural products along the Mississippi and Illinois rivers. The transportation of agricultural products is a key element of agricultural markets. When harvested, these agricultural goods are generally transported from the farm to one of three places: a storage facility, a gathering point where goods are sold and then shipped elsewhere, or to a final destination. The focus here is on the gathering points that include country elevators, rail sub-terminals, and/or barge loading facilities. While storage facilities and final destination points represent alternatives, almost all agricultural commodities are moved through at least one of these gathering points on its way to its final destination which may include export markets, processing plants and feedlots.[7] The data used in this study, described in detail later, represent the transportation decisions of barge loading facilities located along the Mississippi and Illinois rivers. These facilities receive agricultural commodities from farms or other gathering points, and then ship these commodities to another point in the transportation infrastructure.

The theoretical model developed here is a model of competition between grain elevators. This model shows that an elevator's profit maximizing quantity and resulting market area are a function of firm characteristics, characteristics of its rivals and the space that they are competing in. Compared to other modes of transportation, modeling competition between grain elevators located along the Mississippi and Illinois rivers allows for the simplification of modeling elevators as being located in a linear geographic

[7] The focus of this work is on US shipments. As such, the export market is deemed a "final" destination. Obviously, once at the export elevator, there is another set of transportation and marketing decisions; however, this complication is avoided by considering the export market a final destination as the decisions made at this stage of the transportation process are beyond the scope of this study.

space.[8] Specifically, assume that there are $n=1,2,\ldots,N$ elevators located along the river from highest point on the river to lowest point on the river. Further assume that these elevators are located $D=d_{1,2,d2,3},\ldots,d_{n-1,n}$ miles apart from one another, and that grain production per mile is distributed between elevators with parameter y.[9]

Assuming profit maximizing behavior, farmers sell their grain to the elevator e which yields them highest returns net of transportation costs $(w^e + \delta_e - \theta D^e)$ where w^e is elevator e's bid price, δ_e is the farmer's preferences for elevator e, θ is the farmer's cost per unit distance, and D^e is the distance from the farmer's location to elevator e.[10] The farmer's problem then is a decision of where to sell their crops to from a set of locations, which are translated into distances for the current application.[11]

Given farmer's decision making rule given above, consider farmers producing grain who are located between two elevators generically defined as elevator A and elevator B, located D miles apart. The farmer who is indifferent between these two elevators is located at a point such that:

$$D^A = \frac{w^A - w^B}{2\theta} + \frac{\delta_A - \delta_B}{2\theta} + \frac{D}{2} \tag{1}$$

Notice that D^A not only gives the distance of the indifferent farmer from elevator A, but also indicates the share of the market captured by elevator A, i.e. the market areas of elevators A and B. According to equation [1], the distance the indifferent farmer is

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[8] However, this model is general enough to be adapted to non-linear distances.
[9] Note that this assumes that grain is evenly distributed between elevators; however, this model is again general enough to be adapted to a non-even distribution of grain.
[10] δ_e enters this equation to control for non-price differences across farmer's utility functions. For example, one farmer may like the options provided to it by using a large multi-plant companies elevators, while a different farmer may prefer his/her local cooperative elevator to the large corporative elevators.
[11] It is assumed that no one elevator offers a price high enough to price the other elevators out of the market.

from elevator A, D^A, is increasing in the price elevator A offers, $\frac{\partial D^A}{\partial w^A} > 0$, decreasing in the price elevator B offers, $\frac{\partial D^A}{\partial w^B} < 0$, increasing in farmer tastes for elevator A, $\frac{\partial D^A}{\partial \delta_{\mathrm{A}}}$, decreasing in farmer tastes for elevator B, $\frac{\partial D^A}{\partial \delta_B}$, increasing in the distance between the two elevators, $\frac{\partial D^A}{\partial D} > 0$ and ambiguous in the farmer's transportation cost, θ.

While equation [1] describes elevator A's market share, i.e. market area, when competing with elevator B, elevator A also competes with an additional elevator which is located on the other side of elevator A. Put more concretely, these elevators are located linearly along a river implying that each elevator has competitors both up- and downriver from its location. Given this, elevator A's total output is given by the total product produced (*yD*), and its share of the distance between elevator B on one side and elevator C on the other, which are denoted D^{A-B} and D^{A-C} as defined by (1). Mathematically, this means that the total output for elevator A is given by:

$$\begin{aligned} Q^A &= Dy\left\{ \int_0^{D^{A-B}} \frac{1}{D} dt_1 + \int_0^{D^{A-C}} \frac{1}{D} dt_2 \right\} = Dy\left\{ \frac{D^{A-B}}{D} + \frac{D^{A-C}}{D} \right\} \\ &= \frac{y}{2\theta}\left\{ 2w^A - w^B - w^C + 2\delta_{\mathrm{A}} - \delta_{\mathrm{B}} - \delta_C \right\} + \frac{Dy}{2} \end{aligned} \tag{2}$$

According to equation [2], elevator A's output is increasing in the price it offers, but decreasing in the price of its rivals. Further notice that if prices and non-price characteristics are the same, the elevators simply split the market area. If prices are different, then there are a number of effects. First, greater distances between elevators increase total regional output and, hence, the quantity each elevator handles. Second, an increase in farmer transportation costs reduces the effectiveness of pricing differences on the market area, and therefore, the quantity of the higher priced elevator. Of course, since all goods are shipped, it has the effect of increasing the quantity of the lower priced elevator. Finally, as with increases in the distances between elevators, increases in the grain yield result in a larger total market with no change in market area resulting in an increase in production at each elevator. Third, an increase in farmer preferences for elevator A relative to elevators B and C, leads to an increase in elevator A's output.

Equation [2] defines the output of a representative elevator that competes with others over geographic space and provides a deterministic relationship within the model, i.e. there is a unique w^A for a corresponding output level (Q). For the purposes of this paper, it is convenient to invert equation [2] to provide the "bid" price of an elevator as a function of output. The bid price is then given by:

$$w^A = \frac{1}{2}\left\{w^B + \delta_B + w^C + \delta_C\right\} + \frac{\theta}{y}\left\{Q^A - \frac{Dy}{2}\right\} - \delta_A \tag{3}$$

The costs of gathering output through a bid price provide for the costs the elevator incurs to procure the grain for shipments. The costs of procurement are simply the bid-price multiplied by the quantities attracted to the elevator's location. These costs are given by:

$$\begin{aligned} \mathrm{C}^{\text{Procurement}} &= w^A Q^A = w^A(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C)Q^A \\ &= C^{\text{Procurement}}(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \end{aligned} \tag{4}$$

with the properties that marginal costs are positive and increasing in Q.

An elevator with procurement costs given by [4] has additional operating costs which are assumed to be positively related to elevator activity levels (Q), factor prices (z), and non-positively related to fixed asset levels (e.g., capacity, *K*). That is, $\mathrm{C}^{\text{Operations}} = \mathrm{C}^{\text{Operations}}(Q^A, z, K)$. Having defined the individual components of elevator costs, the total cost function of a facility making transportation decisions, is given by:

$$\begin{aligned} \mathrm{C}^{\text{Elevator}} &= \mathrm{C}^{\text{Operations}}(Q^A, z, K) + \mathrm{C}^{\text{Procurement}}(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \\ &= \mathrm{C}(Q^A, z, K, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \end{aligned} \tag{5}$$

Note that the cost function defined by equation [5] includes the bid prices of the firm's rivals. This is not a common treatment of the cost function of shippers, and arises because the model developed here explicitly accounts for the geographic space over which the elevators are competing. However, as long as this cost function has increasing marginal costs, the remainder of the theory applies.

Further notice that for the procurement cost function to be increasing in output is that there is less than a direct matching of price changes by competing elevators, which would lead to no change in quantity.[12] However, the assumption of differentiated services, i.e. farmer preferences over elevators and other elevator attributes which vary including yields, capacity levels, transportation attributes, etc. allow for a non-trivial result.

Given the cost structure derived in equation [5], the firm chooses quantity, Q^A, which implicitly determines w^A given the bid prices, and preferences for its rivals by solving its profit maximization problem:

$$Max\ \pi = (P - t - s)Q - C(Q) \tag{6}$$

where *P* is the price that the elevator gets for the commodity, *t* is the transportation costs associated with shipping the commodity, and *s* is the service characteristics of the

[12] This can be seen by totally differentiating equation [2] and imposing the restriction that price changes are equivalent.

shipment. The solution to the firm's maximization problem represented by equation [6] gives the quantity that the elevator will ship, assuming that larger shipment sizes are harder to procure. There are many ways that the assumption of larger shipments being more difficult to procure can be satisfied; for example, the shipper having to increase its bid prices in order to increase its gathering area or to induce farmers to reach a reservation price. Theoretically, the grain elevator's profit maximizing profit level given by the solution to equation [6] is a function of the price the elevator receives, the transportation rate, service induced costs, and procurement/processing costs determinants:

$$Q^* = Q^*(P, t, s, c, D, y) \tag{7}$$

where c is the set of parameters from the cost function previously derived in equation [5].

Given the first-order condition to equation [6], one can derive comparative statistics for how changes in each of the elements of equation [7] affect the firm's profit maximizing choice of quantity (market area). Increases in P, the price that the elevator receives, the grain per mile produced (y), and the distance between elevators (D) will not decrease the quantity, or market area, of the firm. Alternatively, increases in t or c will not increase the quantity, or market area, of the firm. As for how the individual elements of elements of c, the cost parameter, impact the firm's profit maximizing quantity, increases in factor prices (z) and the bid prices of rivals (w^A and w^B) increase costs, thus reducing both profits and the firm's quantity, or market area, while increases in capacity (K), grain per mile (y) and distance between elevators (D) reduce costs therefore, increasing both profits and the firm's quantity, or market area.

3. Empirical Methodology

Theoretically, the profit maximizing quantity shipped by an elevator was found to be a function of the price that the elevator gets when it ships the commodity, transportation costs of shipping the commodity, the service characteristics of the mode of transportation, the costs of operation, farmer preferences for non-price characteristics of the elevators, crop production, and the distance to competitors. In this section, an empirical model is developed to estimate these relationships.

As noted previously, and discussed in greater detail later, many of the elevators in our sample of data tend to cluster at different points along the river. I model the farmers' decisions as sequential. That is, they first choose a particular cluster of elevators and then choose the specific elevator within a given cluster. In the first case, farmers choose between groups of elevators, and, given the group chosen, farmers choose the specific elevator. The first case is likely generated by geographic space as well as differences in the bid prices. The second case is generated by prices as well as non-price factors. This structure is useful in empirical modeling in that there are a number of cases wherein elevators within a group are extremely close to one another, yet the groups may be some distance away. To account for each of these types of competition, several measures of spatial characteristics are added to equation [7]. These spatial measures are intended to capture both the magnitude of competition and include: the number of firms in the area and the capacity of competing elevators in the area.

Thus far, competition from non-river facilities has been ignored; however, competition from these locations needs to be accounted for in the empirical specification as its intensity is likely to vary along the river. While the output of these non-river facilities is not observed in the data, information on the alternative transportation rate (non-barge rate) for the river terminals is observed, and is added to equation [7] in order to control for competition from off-river facilities.[13] It is also noted that due to geography, or perhaps specialization, elevators' annual output may be comprised of different compositions of grain products (e.g. corn, wheat, soybeans). Because corn is the dominant crop produced in the United States, firms shipping almost exclusively corn should have higher annual ton-miles than firms shipping little to no corn.[14] This is accounted for by adding a variable capturing the proportion of elevator shipments that are composed of corn to equation [7]. Finally, it is noted that there are two general classifications of firms: large conglomerate firms with many locations and independent or cooperative local firms. Any preferences that farmer's may have over these types of firms enters into equation [7] through their non-price preferences, δ. Therefore, a dummy variable for conglomerate firms is added to equation [7] to control for each of these types of firms. Empirically, based on equation [7], and the aforementioned observations, the base model to be estimate is given by:

Annual Ton-Miles = *f* (barge rate, alternative rate, transportation rate from farmer to elevator, distance to nearest competitor, firm capacity, number of firms in the area, capacity of competing firms in the area, dummy variable for large conglomerate firms, area production, % of elevator shipments that are corn) (8)

Where *barge rate* is the rate per ton-mile of the barge movement; *transportation rate from farmer to elevator* is the rate per ton-mile of transporting the commodities, via truck or rail, to the barge loading facility (i.e., in the context of the model presented earlier, it is the farmer's transportation cost); *alternative rate* is the rate per ton-mile of

[13] This is done because the alternative rate (e.g. rail and/or truck) facing the river terminal is likely to be the same as the rate facing non-river elevators.

[14] According to the USDA, corn production in 2000 was almost exactly twice the combined sum of wheat and soybeans.

the most common alternative to shipping down the river, an element of mode choice from our theoretical section; *distance to nearest competitor* is the distance to the nearest competitor; *capacity* is the capacity in bushels of the firm; *number of firms in area* in the number of competing elevators in the same pool; *capacity of firms in area* is the capacity of the firms in the same pool; *area production* is the average production of the commodity in the elevator's county and bordering counties; *% of elevator shipments that are corn* is the proportion of total shipments that are corn; and the *dummy variable for large conglomerate firms* is a dummy variable equal to 1 if the shipper is one of the six conglomerate firms in the sample. [15]

Equation [8] is specified in a double log form and estimated using both ordinary least squares (OLS) and a fixed effects model (FE). The fixed effects model allows the intercept of equation [8] to vary by "pool" along the river. A pool is a body of water between two fixed points. In this case, a pool is the body of water between two locks.[16] The purpose of the fixed effects specification in this context is to capture any unobserved differences in pools that influences elevator output, but which is unobserved in the data.

In equation [8], the effect of increases in both the barge rate (the law of demand) and the transportation rate (θ in our theory) are expected to be negative. It is also expected that an increase in the distance to the nearest competitor (*D* from our theory) will increase annual tonnages. Capacity should also increase production, the number of firms in the area has an ambiguous effect (it increases competition which should decrease quantity, but farmers from far distances are more likely to ship to an area where there are

[15] A pool is the area between two locks on the river.

[16] In Army Corps of Engineer modeling efforts, demands are typically defined at the pool level. That is, they consider the originating-terminating and commodity triple as a demand function that enters into their planning models.

many choices and then choose which to use when they arrive), the capacity of the firms in the area is predicted to have a negative effect because larger firms in the area means stronger competition, and area production (y from our theory) should have a positive effect.

Recognizing that these data represent grain elevators located over a vast geographic space, rolling regressions and locally weighted regressions techniques are used along with parametric interaction terms and endogenous switch points to examine the geographic patterns of barge demand elasticity. Additionally, as a robustness check, a model of spatial autocorrelation is estimated to allow for the possible spatial clustering of errors. For expedience, each of these models is discussed in detail below with a description of the results.

4. Data

The data used in this study contain information on river port elevators. These data were obtained from the Tennessee Valley Authority (TVA) who, during two sets of personal interviews of barge terminals located along American's inland waterways, collected information regarding each elevator's annual tons shipped, commodities shipped, barge charges, truck transfer charges, the termination of the shipments, average gathering area of product to be shipped, alternative routes that they could have sent that shipment if not by barge, and various other firm characteristics. A subset of these data is employed for this analysis. In particular, the activities of the 103 grain elevators located on the Upper Mississippi and Illinois rivers are examined.

Figure 1 visually depicts these 103 elevators.[17] Unlike many previous theories of spatial competition assume, these elevators are not uniformly distributed along the

[17] The TVA data were matched with the USACE Port Series database to obtain these terminal locations.

waterway system. Instead, there are large groupings, or clusters, of firms at some locations and single elevators elsewhere. One explanation for this clustering of firms lies in differences in crop production along various stretches of the river. Alternatively, river characteristics, such as the location of locks along the river, rail connection points, land prices, and appropriateness of the land for elevator operations, etc., may also have influenced the location of firms.

The data also provide for the average distance goods travel to the facility before being loaded to barge. This is the "gathering area" of the elevator. Figure 2 shows the median gathering areas for groupings of firms. These gathering areas were calculated by first grouping the elevators together according to their location along the river and then calculating the median gathering area of the elevators in each grouping. These median gathering areas were then graphed in the center of the geographic group.

Variables

From equation [8], the dependent variable for this study is *annual ton-miles* which is defined as the annual-tons shipped multiplied by the distance of the shipments.[18] The right-hand side variables include: the *barge rate* defined as the barge charge per ton divided by the miles of the movement; the rate *transportation rate from farmer to elevator* is defined as the transportation rate per ton, via truck or rail, to the barge loading facility divided by the miles transported to the elevator; *alternative rate* is the rail, truck and/or barge rate per ton-mile of the next best alternative to shipping down the river; *distance to nearest competitor* is the distance, in miles, to the nearest competitor either

[18] Tonmiles is the traditional measure of output in the transportation literature. An alternative output measure is tonnage; however, transportation occurs over space, and one ton moved ten miles is much different then one ton moved 1000 miles.

up-steam or down-steam; *capacity* is the capacity in bushels of the firm; *number of firms in area* in the number of competing elevators in the same pool; *capacity of firms in area* is the capacity of the firms in the same pool minus the elevator's own capacity; *area production* is taken from the USDA's county level crop output database, and is defined as the average production of the commodity being shipped in the elevator's county and bordering counties; *% of shipments that are corn* is defined as the number of annual corn shipments divided by the total number of shipments; and the *dummy variable for large conglomerate firms* is a dummy variable equal to 1 if the shipper is one of the six conglomerate firms in the sample. Summary statistics for each of these variables along with the reported gathering area of the elevators are provided in Table 1. For this study, all variables (except for the distance to the nearest competitor, the number of firms in the area, the % of shipments that are corn and the conglomerate dummy variable) are estimated in logs.[19]

These descriptive statistics provided in Table 1 suggest that there is considerable variation in annual ton-miles shipped. That barge rate per ton-mile is much smaller than the alternative rates (rail and truck), and that rates from the farmer to the elevator are approximately 7 times higher than the barge rates, but much less than the alternative rate, owing to shorter distances. Firm capacity and area capacity vary quite a bit from elevator to elevator. The distance between elevators is about 2.5 to 7.7 miles, while the number of firms in the same area appears to be approximately 5. There also appears to be considerable variation in the area production of crops. Finally, the gathering area (the distance of inbound shipments) has a median value of 60 miles and an average value of about 71.1. Further, a simple regression of gathering area and river mile indicates that

[19] These variables are not estimated in logs because they take values of zero.

gathering areas increase with river mile, and a 100 mile increase in river mile increases gathering areas about 4 miles. From the lower reaches of the river to the most northern areas, this suggests a difference in gathering area of approximately 33 miles.[20]

5. Results

Table 2 presents the results of running the base model specified by equation [8] using both OLS and fixed effects. The first two columns of results are from the OLS specification (with and without the observable regional characteristics variables), while columns 3 and 4 are from the fixed effects specification. While the fixed effects models fit the data better with r-square values of .5 and .53 versus .36 and .4, tests for the appropriateness of the fixed effects conclude that they are not warranted at any standard level of significance.

The estimated elasticity of barge demand is negative and significant in all four models with fairly similar estimates of: -1.414 (OLS without spatial controls), -1.614 (OLS with spatial controls), -1.508 (fixed effects without spatial controls), and -1.799 (fixed effects with spatial controls). The transportation rate from the farmer to the elevator (θ from the theoretical model) is also negative and significant in all models indicating that as the cost of transporting crops to the river elevators increase, the quantity shipped by the elevator decreases as was predicted by the theoretical model. Area production, y in the theoretical model, is positive and significant in both of the spatial control models indicating that as the crop production in the elevators' county and neighboring counties increases, the river elevators ship more. The percent of shipments that are corn is also positive and significant across all specifications indicating that firms

[20] Anderson and Wilson (2004) theoretically show that this should be the case, as farmers are willing to transport a further distance to the river in order to take advantage of the relatively cheaper barge transportation as the distance to be traveled increases.

who specialize in corn shipments, whether it be because of geography or specialization, ship more annual ton-miles of corn. The estimated coefficients on capacity and the conglomerate dummy variable are both positive across all specification; however, the effect of capacity is only significant in the OLS spatial control specification and the effect of the conglomerate dummy is only significant in the OLS specifications.[21] These results indicate that elevators that are part of large national conglomerate firms and firms with higher capacity levels ship more annual ton-miles. Note that in the spatial control fixed effects model the effect of the number of firms in the pool is not estimated as it does not vary within the pool. All other variables from equation [8] are statistically insignificant across all specifications.

Geographically Varying Elasticity Estimates

All specifications in the base model presented in Table 2 restrict the elasticity of barge demand to be constant across all observations. However, given that the alternatives confronted by spatially distributed river facilities differ, the constant elasticity assumption may not be appropriate. To see this point, recall from the theoretical section that grain elevators procure their commodities from farmers. To the extent that farmer's have different shipping options at different locations along the river, the effect of changes in the barge rate on the quantity shipped, i.e. the elasticity of barge demand, may vary along the river. For example, a farmer with no rail service or nearby country elevators may respond to a decrease in the bid price of an elevator (equivalent to an increase in the barge rate faced by the elevator) by not changing their quantity supplied. Alternatively, a farmer who is either close to other river elevators or is close to a country elevator with rail service to an alternative destination market (e.g. the Pacific Northwest) may respond

[21] The effect of these variables may be captured in the fixed effect coefficients.

to the lower bid price (higher barge rate) by sending all crops to a different facility. Therefore, theoretically, barge demand elasticity may vary along the river. However, the exact form of this variability is unknown prior to estimation.

As an initial examination of the pattern of geographic barge demand elasticity, rolling regressions and locally weighted regressions techniques are employed. In each of these models, the data are ordered in ascending order according to river mile. The model given by equation [8] is then run on subsets of the data, with the difference between the two models being how the subset is used in the estimation process.

Rolling regressions were first developed by Fama and MacBeth (1973) and Officer (1973) to study time series data. These models were developed to see how the same relationship changed over time; however, the same methodology can be employed over geographic space where there is a natural ordering to the spatial variable. In this case, the location of the elevators is available according to river mile (miles from a point on the river). This measure then provides a natural ordering which is then used to apply the rolling regression methodology. The result allows an empirical representation of how transportation demands vary over geographic space. In the rolling regressions model, the estimation equation, as specified above in equation [8], is run on a user specified "window" of data.[22] In practice, the barge demand equation is run on the first x observations (geographically) and the demand elasticity is recorded, where x is the specified window size. Note that x is arbitrarily chosen, and the only restriction on it is that it must be large enough to estimate the equation. The barge demand equation is then run on observations 2 through $x+1$ and the estimated demand elasticity from this equation is recorded. The equation is then run on 3 through $x+2$, 4 through $x+3$, etc. In essence, a

[22] The size of the window (x) is arbitrary, and thus various specifications of the window size are run.

window of size *x* is moved along the river one position at a time estimating the demand elasticity for each window location.

The second technique used in this study to examine barge demand elasticity over space is the locally weighted regressions model developed by Cleveland (1979). This technique is similar to the rolling window technique just described with one notable difference. As with rolling regressions, the locally weighted regressions procedure also requires the econometrician to specify a window size over which the demand equation is estimated and, again, the window moves up the river one position at a time. The key difference is that the observations in the window are weighted such that the middle position gets the highest weight and each position away from the middle gets subsequently lower weights. For example, if a window size of 5 was specified, the middle position would be the 3^{rd} observation in the window and it would receive a weight of 1, indicating that it is fully weighted. Positions 2 and 4 would receive a weight of .89 each, positions 1 and 5 would receive a weight of .35 each, and positions 0 and 6 would receive a weight of 0 meaning that they are not included in the regression. Note that this weighting scheme is the tricube weight proposed by Cleveland *(9)*. Weighted least squares is then used to estimate the demand elasticity for the given middle location and window size. The estimated elasticity is then recorded and the window is moved up the river one location and estimated again. This procedure is designed to give a more "localized picture" of the estimated barge demand elasticity at any given point along the river.

Figures 3 and 4 provide a graphical representation of the results for a window size of 40 (x = 40) for the rolling regressions technique and the locally weighted regressions model respectively. Because of the sample size of the data used is relatively small, the elasticity results are not “precisely measured”, but the patterns bear a strong resemblance and are used to specify parametric forms below. Generally, elasticities tend to be higher in magnitude in the southern and extreme northern parts of the river, and lower in magnitude (relatively, more inelastic) in the middle section of the river.

This pattern of geographic elasticity arises because of several distinct features of the river system. First, farmers and country elevators located on the southern reaches of the river system, have the shortest distance to be traveled by river, and therefore may either use a different mode of transportation, or bypass the lock system by putting their commodities on the river at a more southern point. As for the northern segments of the river, which are also more responsive to barge rates, the inverse pricing rules employed by railroad companies in Minnesota and North Dakota will tend to increase the alternatives of farmers and country elevators in this region as shipping to the Pacific Northwest via rail becomes more feasible, which also increases the elasticity of barge demand in this region. Finally, shippers located towards the central portions of the river system have long distances to travel via any mode, and therefore, with fewer options available, are less responsive to changes in the barge rate.

In addition to the two approaches just described, two parametric models are used to estimate geographically varying barge demand elasticity. The first parametric approach used is the interaction of barge rate with river mile and various higher degree polynomials of river mile in an attempt to capture the relevant systematic patterns along each river. The results of this technique are presented in Table 3, Figure 5 for the Upper Mississippi River, and Figure 6 for the Illinois River. This parametric approach to estimating geographically varying elasticity estimates has the advantage of allowing the exact form of elasticity to be flexibly estimated rather than user imposed. However, using interaction terms has the disadvantage of forcing elasticity to vary *systematically* along the river. The results of these models indicate that the same pattern of elasticity exists for both the Upper Mississippi and Illinois rivers. Specifically, Figures 5 and 6 suggest that barge demand elasticities are relatively more elastic on both the southern and northern ends of the rivers, while elasticity is relatively more inelastic towards the center.

In all cases, the rolling, weighted and varying coefficient models provide relatively wide ranges of elasticity that depend on the spatial location of shippers on the river. In all cases, the pattern is relatively the same. However, perhaps, owing to the relatively small number of observations, statistical significance is generally scant. One final procedure, endogenous switching point models, is used to more carefully examine the patterns of elasticity along the river. In practice, equation [8] is run on the entire sample allowing the elasticity to vary between the Mississippi and Illinois rivers.[23] To find any switch points, an additional dummy variable is interacted with barge demand for every possible point of segmentation of the waterway system i.e., every observation. For example, suppose that there are 5 elevators on the river. According to this endogenous switch point model, equation [8] would be run 4 times, once for each possible break point.[24] The break point that yields the highest level of significance is then chosen as the first break point (F-tests are used to evaluate the significance levels). Given this break point, an additional dummy variable is interacted with barge rate in equation [8] allowing

[23] Tests indicate that that the Mississippi and Illinois barge elasticities are, in fact, different at the 99% level.

[24] The possible break points would be at elevator 2 (meaning that elevator 1 and elevators 2-5 have different elasticities), elevator 3, elevator 4, and elevator 5.

the elasticity to vary between the Mississippi River, the Illinois River and the two subsets of data defined by the break point found.[25] The process is then started over to determine if there are additional switch points present in each subset.

When applied to the data, this method finds that there are six break points which provide six different elasticity estimates, on the Upper Mississippi and Illinois Rivers. To control for these break points, dummy variables, interacted with barge rate, are added to equation [8]. The specification of these dummy variables is outlined in Table 4. Table 5 presents the elasticity estimates obtained from this break point methodology. On the Upper Mississippi River, Figure 7, barge demand elasticity is found to varying between -1.448 and -1.987. Similar to the results found from the previous parametric approach of interacting barge rate and river mile, these results indicate that barge demand is more elastic on the southern (-1.815) and northern (-1.987) ends of the river as compared to the center of the Upper Mississippi River (-1.668, -1.702 and -1.448). For the Illinois River, Figure 8, elasticity varying very little between the two sections of the river as indicated by the endogenous switch point method, with elasticity being -1.869 below lock 5 and -1.874 above lock 5.

Spatial Autocorrelation

Again noting the spatial nature of these data, a spatial autocorrelation model is estimated as a robustness check of the results. A spatial autocorrelation, or spatial error, model as described by Anselin (1988) relaxes the OLS assumption of the independence

[25] The specific break point is at the pool level for the break point that yields the largest test statistic.

of error terms to account for unobserved spatial similarities of elevators.[26] In particular, the spatial error model is given by:

$$\begin{aligned} y &= X\beta + \varepsilon \\ \text{where } \varepsilon &= \lambda W\varepsilon + u \end{aligned} \quad (9)$$

where y is the n by 1 vector of elevator annual ton-miles and X is an n by k vector of the explanatory variables present in equation [8]. Notice that this equation is no different than the OLS specification of equation [8]. However, to this equation structure is added to the error term by specifying that errors are correlated across space rather than being independent. Specifically, the error term is augmented by $\lambda W\varepsilon$, where W is a row standardized spatial weight matrix which relates the errors of observations across space. The particular form of this weight matrix for this study is given by:[27]

$$W_{i,j} = \begin{cases} 0 \text{ if } i = j \\ \dfrac{1}{1+d_{i,j}} \text{ if } i \neq j \end{cases} \quad (10)$$

where $d_{i,j}$ is the degree of contiguity between pools i and j. In particular, pools i and j are first degree contiguous, $d_{i,j} = 1$, if pools i and j share a border, pools i and j are second degree contigous, $d_{i,j} = 2$, if pools i and j are separated by one pool, etc. Notice that zero weight is given to all diagonal elements of the weighting matrix to prevent the error term from being a function of itself.

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[26] The alternative spatial model would be the spatial autoregressive, or spatial lag, model. This model is appropriate when the econometrician believes that there is a direct relationship between dependent variables over space. This model was estimated and the results are nearly identical to those presented for the spatial error model; however, test statistics for the appropriateness of this model indicated that there was no such direct relationship between the dependent variables over space, thus the results of this model are not presented, but are available upon request.

[27] However, other specifications of the weight matrix were examined and did not qualitatively change the results presented. Row standardization is done such that the sum of each row of the spatial weight matrix sums to one, which places the least structure on the spatial specification of the error terms.

Due to the non-spherical error term of the spatial error model, OLS techniques are unbiased, but are inefficient. Therefore, maximum likelihood (ML) techniques are used as is common in the spatial econometric literature. The log-likelihood function of the spatial error model is given by:

$$L = -\frac{n}{2}\ln(2\pi) - \frac{n}{2}\ln\sigma^2 + \ln\left|I - \lambda W\right| - \frac{1}{2\sigma^2}\left[\left(y - X\beta\right)'\left(I - \lambda W\right)'\left(I - \lambda W\right)\left(y - X\beta\right)\right] \quad (11)$$

where $\left|I - \lambda W\right|$ is the determinant of the Jacobian expressing the spatial transformation of the disturbance term.[28] The existence of this Jacobian term in equation [11] complicates the numerical optimization of the likelihood function as this requires calculating the determinant of an *n* by *n* matrix. However, Ord (1975) shows that this Jacobian can be expressed as a function of the eigenvalues, ω_i, of the spatial weighting matrix according to:

$$\left|I - \lambda W\right| = \prod_{i=1}^{N}(1 - \lambda\omega_i) \quad (12)$$

The advantage of this calculation being that it only has to be done once.

This model is estimated both with constant elasticity and with geographically varying elasticity with break points from the endogenous switching point model. The non-elasticity results of this specification are presented in Table 6, while the elasticity estimates are presented separately in Table 7. The results of each of these models do not suggest any improvement in precision by modeling the spatial autocorrelation. This result adds credence to the observable spatial control variables included in equation [8], in that they capture the local competitive environment of grain elevators well enough that

[28] The log likelihood function given by [11] differs from the log likelihood function of a non-spatial linear regression model through this Jacobian term.

the spatial autocorrelation model, which is designed to capture unobserved spatial characteristics, is found to be unwarranted.

Additionally, the results of the spatial autocorrelation model are qualitatively equivalent to those previously found via OLS and fixed effects. The elasticity estimates from the spatial autocorrelation specification are shown in Table 7, Figure 9 for the Upper Mississippi River, and Figure 10 for the Illinois River. Under the assumption of constant elasticity, the barge demand elasticity is estimated to be -1.607. Using the endogenous switch point elasticity method, barge demand is estimated to be between -1.350 and -1.562 for the Upper Mississippi River and -1.558 and -1.592 for the Illinois River. Examining the patterns of elasticity in Figures 9 and 10, the same patter of barge demand is found, where demand is estimated to be more elastic on the southern (-1.542) and northern (-1.562) ends of the Upper Mississippi River and more inelastic towards the center (-1.350, -1.374 and -1.556). For the Illinois River, barge demand is slightly more elastic above lock 5, -1.592, as compared to below lock 5, -1.558.

6. Conclusion

The aim of this study was to develop a theoretical model of spatial demand and the subsequent barge transportation demand of grain elevators, and to obtain estimates of the elasticity of barge demand. These estimated demand elasticities are of particular importance due to the current controversy over the assumptions on the magnitude of barge demand elasticity made in current policy planning models. This study finds elasticity estimates between -1.350 and -1.987, estimates which leads to the conclusion that the assumption of perfectly inelastic transportation demand made by the planning models is inappropriate and may lead to erroneous benefit estimation.

This study also examined the existence of non-constant geographically varying elasticity. To obtain the appropriate geographic pattern of barge demand elasticity along the waterway system, both rolling regressions and locally weighted regressions models were used to first visually examine the data. Two parametric approaches were then used to obtain estimates of barge demand elasticity along the Upper Mississippi and Illinois Rivers. The first of these parametric approaches showed that the barge demand elasticity does not vary systematically along the waterway system. The second parametric approach allowed break points to be endogenously determined, and found 4 break points on the Upper Mississippi River and 2 break points on the Illinois River. Using these endogenous break points, barge demand was found to be more elastic on the northern and southern ends of the Upper Mississippi River as compared to the center of the river.

Finally, a model of spatial autocorrelation was used as a robustness check of the results. The results of this model indicate that errors are not spatially correlated, and provide evidence that the observed spatial competition variables capture the local competitive atmosphere.

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List of Tables and Figures:

FIGURE 1: Barge Terminal Locations of Grain Shippers

Locations of the grain elevators located along the Upper Mississippi (North of Cairo, IL.) and Illinois Rivers.

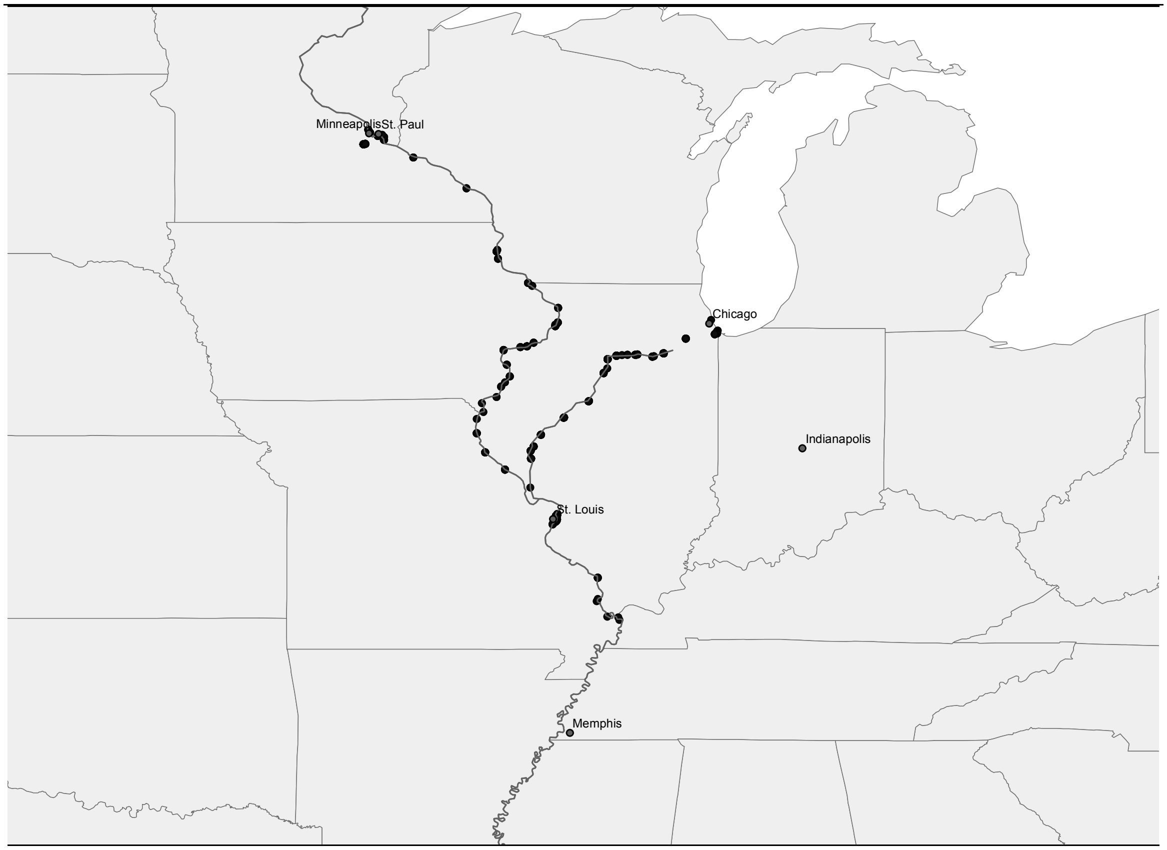


FIGURE 2: Median Gathering Areas

The firm's gathering defined as the distance that they report procuring crops from. The elevators are then grouped by river segment and the median gathering area of these groups is calculated.

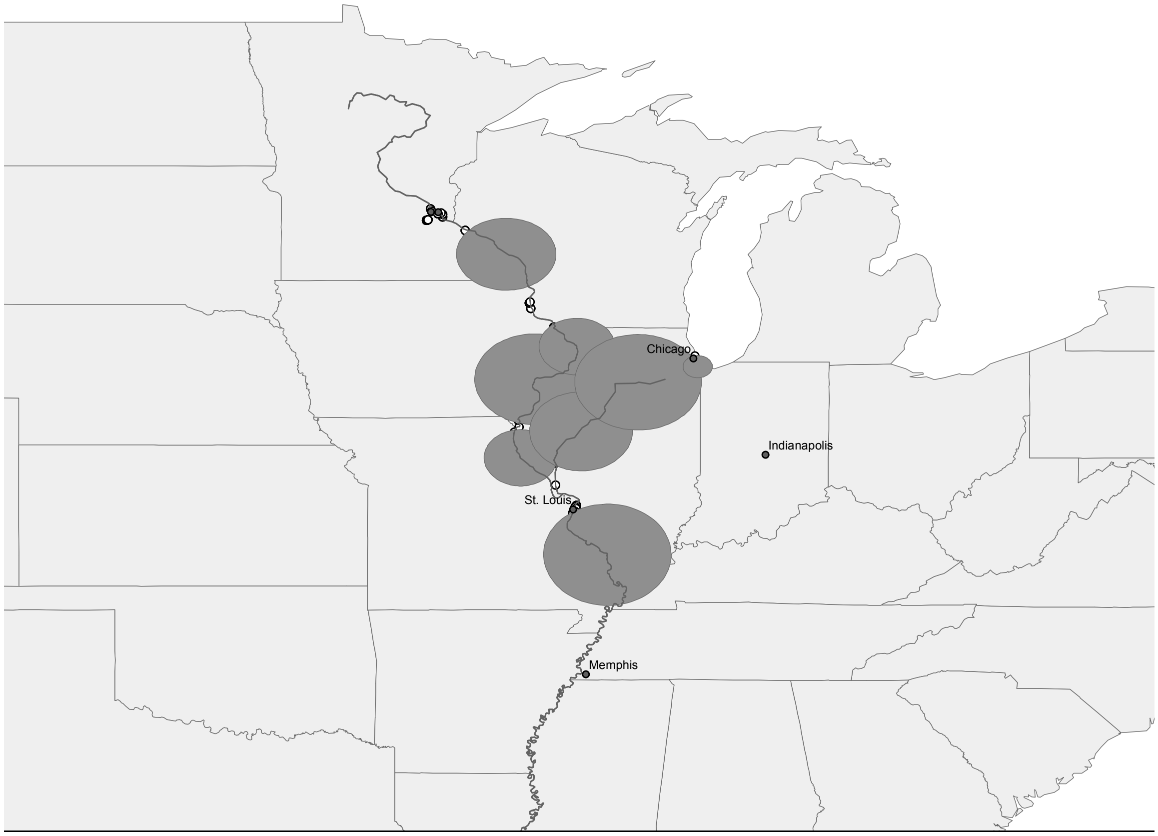


TABLE 1: Descriptive Statistics

The sample of 103 observations of grain elevators on the Upper Mississippi and Illinois Rivers collected via survey by the Tennessee Valley Authority (TVA). Annual ton-miles is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments. Barge rate is the barge charge per ton divided by the miles of the movement. Transportation Rate to Elevator is the rate per ton (via truck or rail) to the barge loading facility divided by the miles transported to the elevator. Alternative Rate is the rail, truck and/or barge rate per ton-mile of the next best alternative to shipping down the river. Firm Capacity is the capacity, in bushels, of the firm. Distance to Nearest Competitor is the distance, in miles, to the nearest competitor either upstream or downstream. Area Capacity is the capacity of the firms in the same pool minus the firm's own capacity. Number of firms in the Area is the number of competing elevators in the same pool. Area Production is taken from the USDA's county level crop output database, and is defined as the average production of the commodity being shipped in the elevator's county and bordering counties. % of Shipments that are Corn is the number of annual corn shipments divided by the total number of shipments. Gathering Area is the distance the commodity traveled to arrive at the river port barge loading facility.

Variable	Centile	Average
Annual Ton-Miles (thousand)	15,400	47,800
Barge Rate	0.012	0.011
Transportation Rate to Elevator	0.091	0.099
Alternative Rate	0.129	0.131
Firm Capacity (thousand)	550	1,505
Distance to Nearest Competitor	2.5	7.69
Area Capacity (thousand)	2,020	4,119
Number of Area Firms	5	4.6
Area Production (thousand)	47,500	61,100
% of Shipments that are Corn	0.5	0.454
Gathering Area	60	71.1

TABLE 2: Results of Annual Ton-Mile Regressions Using OLS and FE Models

The dependent variable, Log(Annual Ton-Miles) is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments.

	OLS without Regional Characteristics	OLS with Regional Characteristics	Pool Fixed Effects without Regional Characteristics	Pool Fixed Effects with Regional Characteristics
Log (Barge Rate)	-1.414** (0.583)	-1.614*** (0.597)	-1.508** (0.635)	-1.799*** (0.648)
Log (Transportation Rate to Elevator)	-1.241** (0.550)	-1.236** (0.565)	-1.520** (0.633)	-1.674*** (0.628)
Log (Alternative Rate)	-0.365 (0.746)	-0.192 (0.749)	-0.486 (0.866)	-0.082 (0.874)
Log (Capacity)	0.166 (0.114)	0.205* (0.118)	0.288 (0.210)	0.330 (0.366)
Conglomerate Firm Dummy Variable	0.969*** (0.330)	0.863** (0.337)	0.514 (0.438)	0.427 (0.453)
% of Shipments that are Corn	1.859*** (0.409)	1.396*** (0.461)	1.749*** (0.449)	1.400*** (0.504)
Log (Pool Capacity)		-0.058 (0.045)		0.193 (0.656)
Log (Area Production)		0.128** (0.062)		0.124* (0.066)
Distance to Nearest Competitor		-0.023 (0.017)		-0.036 (0.029)
Number of Firms in Same Pool		0.066 (0.081)		
Constant	2.576 (2.943)	0.261 (3.349)	-0.029 (4.187)	-5.555 (13.078)
Observations	103	103	103	103
Pools			23	23
R^2	.36	.40	.50	.53

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 3: Rolling Regressions Estimates with Window Size 40

Elasticity estimates using a rolling regressions estimation technique (see text for details) of the model presented in Table 2 with a window size of 40. Other window sizes were used and the results are available from the author upon request.

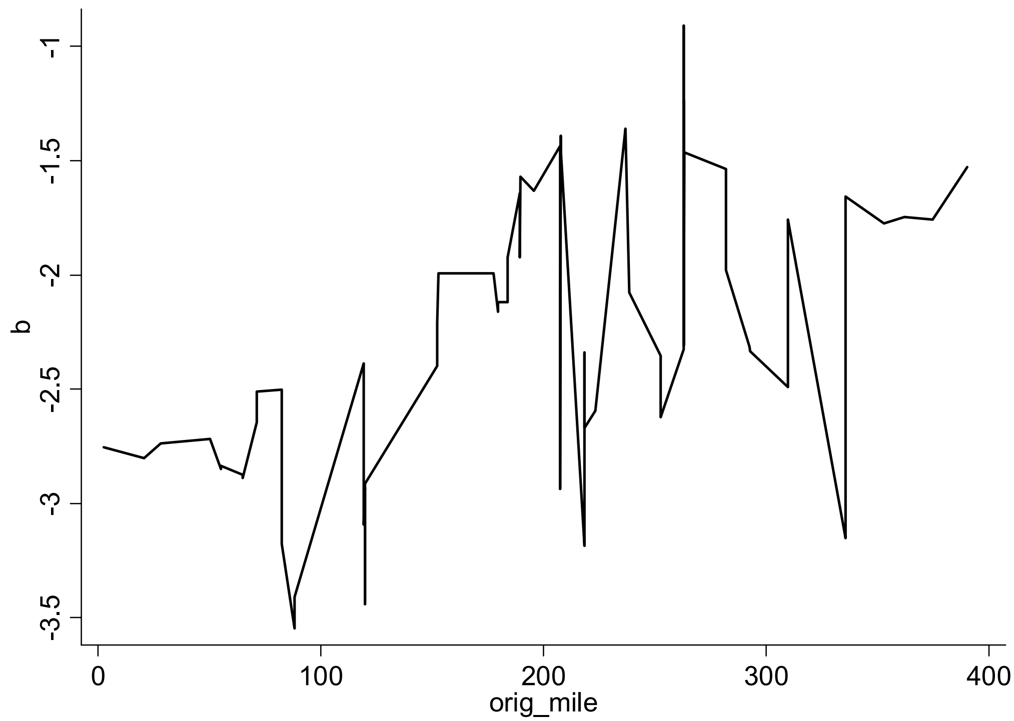


FIGURE 4: Locally Weighted Regressions Estimates with Window Size 40

Elasticity estimates using a locally weighted regression estimation technique (see text for details) of the model presented in Table 2 with a window size of 40. Other window sizes were used and the results are available from the author upon request.

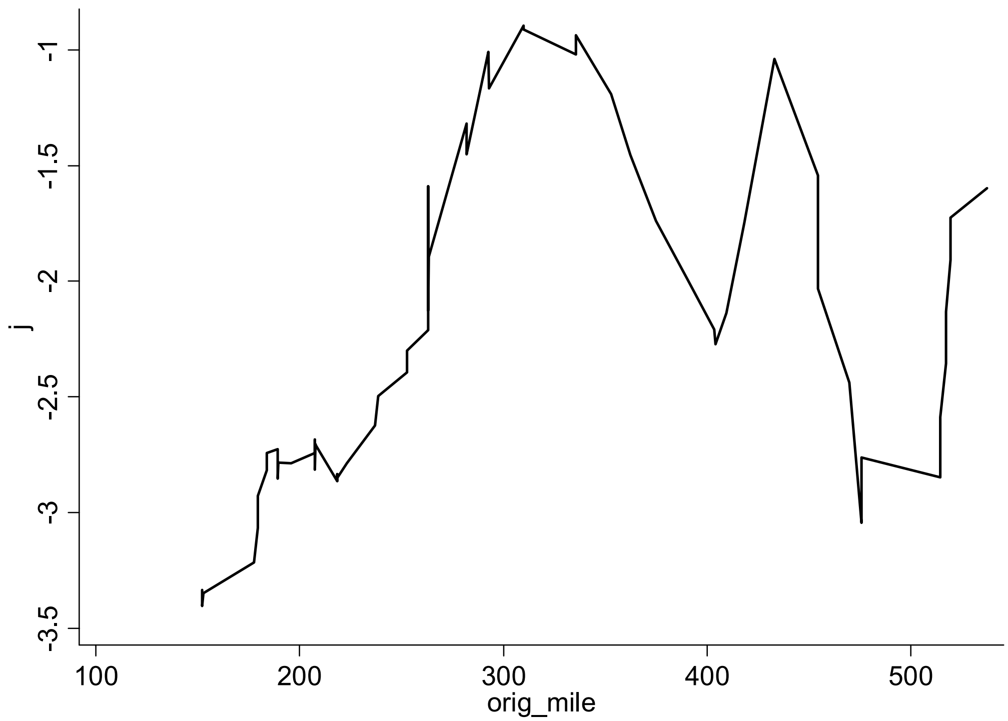


TABLE 3: Parametric Geographically Varying Elasticity Estimates

Using interaction terms of river mile with elasticity, geographically varying elasticity estimates of the same model presented in Table 2 for each river system.

Model	Barge Rate Estimate	Barge Rate Interacted with River Mile Estimate	Barge Rate Interacted with River Mile Squared Estimate	Barge Rate Interacted with River Mile Cubed Estimate
Upper Mississippi River				
Constant Elasticity	-1.574** (0.603)			
Linear Elasticity in River Mile	-1.390** (0.626)	-0.0002 (0.0002)		
Quadratic Elasticity in River Mile	-1.611** (0.660)	0.0007 (0.0009)	-0.000002 (0.000002)	
Cubic Elasticity in River Mile	-1.681** (0.661)	-0.003 (0.002)	0.00002 (0.00001)	-0.00000002 (0.00000001)
Illinois River				
Constant Elasticity	-1.632*** (0.600)			
Linear Elasticity in River Mile	-1.593** (0.618)	0.0003 (0.0007)		
Quadratic Elasticity in River Mile	-2.059*** (0.669)	0.007* (0.004)	-0.00004 (0.00003)	
Cubic Elasticity in River Mile	-1.854*** (0.696)	-.008 (0.011)	0.0002 (0.0001)	-0.0000006 (0.0000004)

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 5: Parametric Varying Elasticity Estimates for the Upper Mississippi River

Using interaction terms of river mile with elasticity, geographically varying elasticity estimates of the same model presented in Table 2 for the Upper Mississippi River system.

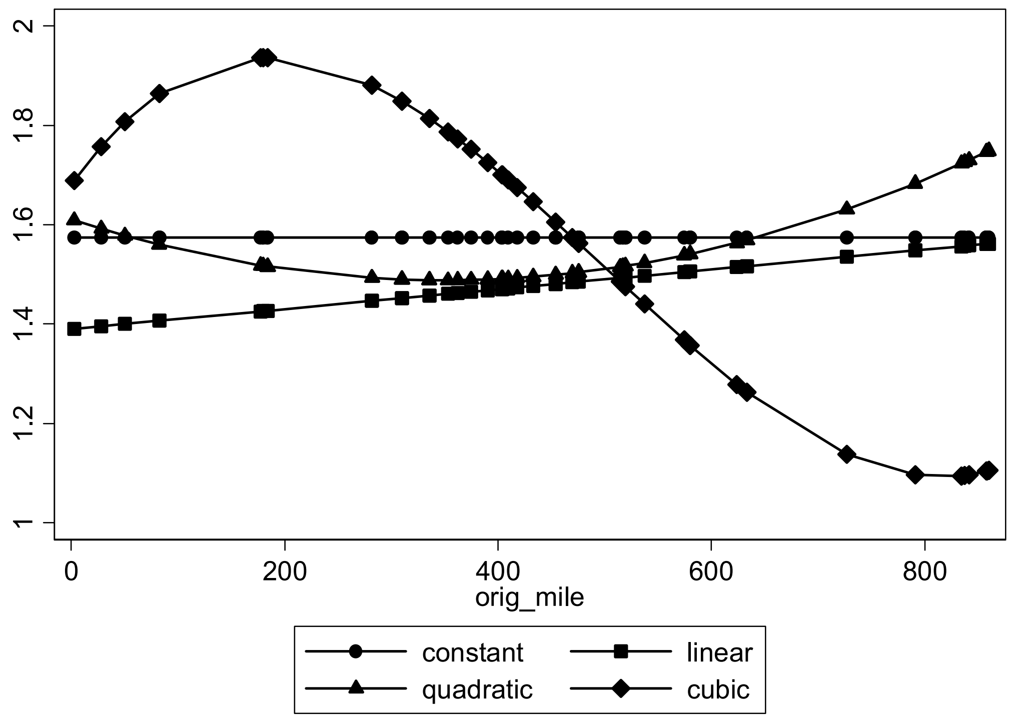


FIGURE 6: Parametric Varying Elasticity Estimates for the Illinois River

Using interaction terms of river mile with elasticity, geographically varying elasticity estimates of the same model presented in Table 2 for the Illinois River system.

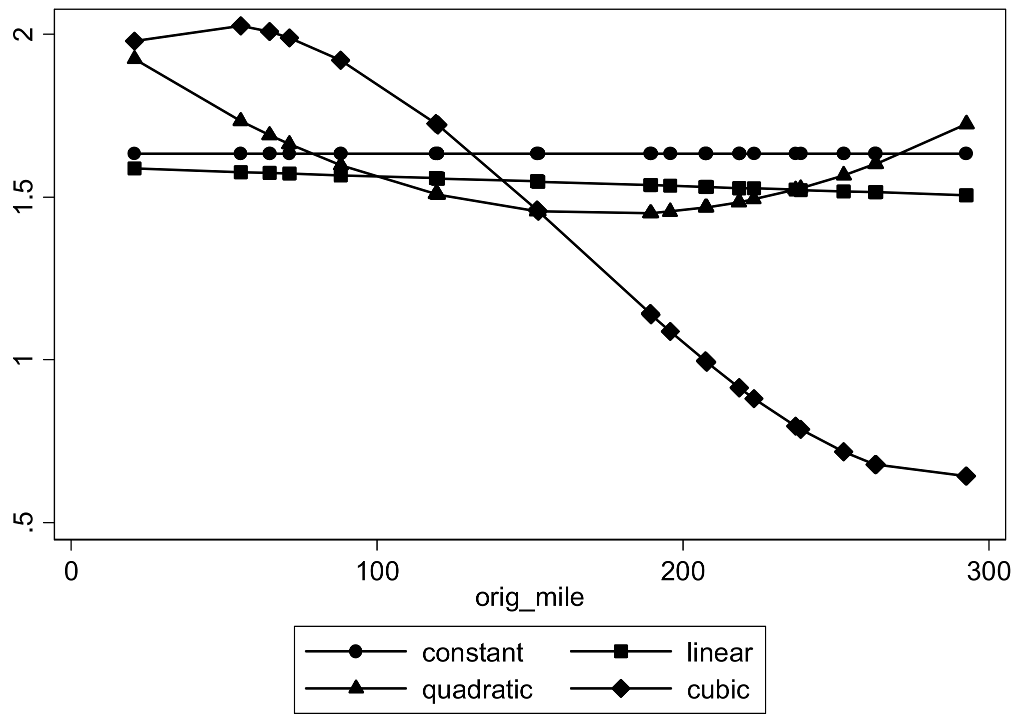


TABLE 4: Definition of Elasticity Dummy Variables along the Waterway System

Using an endogenous switch point methodology (see text for details), there were six regions of elasticity found along the waterway system.

Grouping	River Segment
1	Illinois River Below Marseilles Lock (Mile 244.6)
2	Illinois River Above Marseilles Lock (Mile 244.6)
3	Upper Mississippi River Below Lock 27 (Mile 185.5)
4	Upper Mississippi River Between Locks 27 (Mile 185.5) & 16 (Mile 457.2)
5	Upper Mississippi River Between Locks 16 (Mile 457.2) & 10 (Mile 615.1)
6	Upper Mississippi River Between Locks 10 (Mile 615.1) & 2 (Mile 815.2)
7	Upper Mississippi River Above Lock 2 (Mile 815.2)

TABLE 5: Endogenous Switch Point Elasticity Estimates from OLS

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for each river system.

Upper Mississippi River

	Below Lock 27	Between Locks 27 & 16	Between Locks 16 & 10	Between Locks 10 & 2	Above Lock 2
Elasticity	-1.815***	-1.668***	-1.702***	-1.448**	-1.987***
	(0.640)	(0.611)	(0.604)	(0.608)	(0.617)

Illinois River

	Illinois River Below Lock 5	Illinois River Above Lock 5
Elasticity	-1.869***	-1.874***
	(0.611)	(0.618)

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 7: Regional Elasticity Estimates for the Upper Mississippi River from OLS

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Upper Mississippi River system.

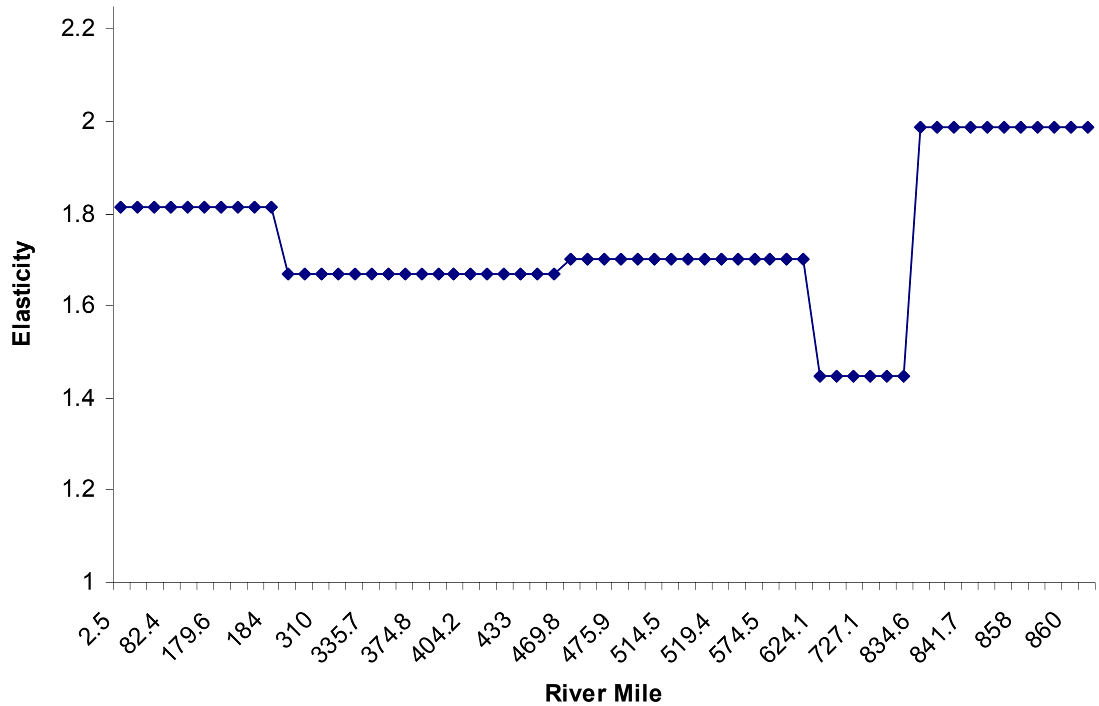


FIGURE 8: Regional Elasticity Estimates for the Illinois River

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Illinois River system.

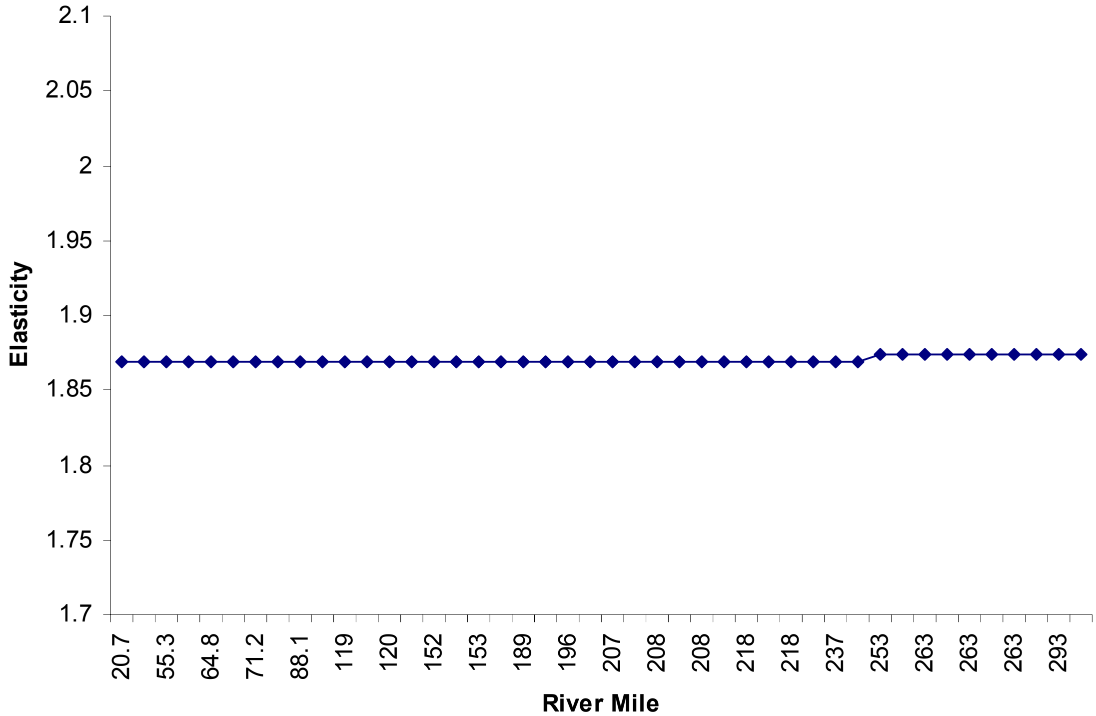


TABLE 6: Non-Elasticity Results from the Spatial Autocorrelation Model

The dependent variable, Log(Annual Ton-Miles) is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments. The geographic elasticity model is estimated using the elasticity regions defined by Table 4. The weighting matrix used for the spatial autocorrelation model is defined as (see text for details):

$$W_{i,j} = \begin{cases} 0 \text{ if } i = j \\ \frac{1}{1+d_{i,j}} \text{ if } i \neq j \end{cases}$$

where $d_{i,j}$ is the degree of contiguity between pools i and j, i.e. pools i and j are first degree contiguous, and $d_{i,j}$ =1 if they share a border, second degree contiguous, $d_{i,j}$ = 2 if they are separated by 1 pool, etc.

	Constant Elasticity	Geographically Varying Elasticity
Log (Transportation Rate to Elevator)	-1.177** (0.555)	-1.048* (0.588)
Log (Alternative Rate)	-0.242 (0.721)	-0.365 (0.747)
Log (Capacity)	0.209* (0.111)	0.279** (0.135)
Log (Pool Capacity)	-0.056 (0.042)	-0.077* (0.046)
Number of Firms in Same Pool	0.070 (0.075)	0.021 (0.096)
Log (Area Production)	0.129** (0.059)	0.143** (0.061)
Distance to Nearest Competitor	-0.022 (0.016)	-0.025 (0.017)
% of Shipments that are Corn	1.385*** (0.436)	1.131** (0.457)
Conglomerate Firm Dummy Variable	0.847*** (0.322)	0.714** (0.327)
Constant	0.208 (3.133)	0.235 (3.208)
Lambda	-0.106 (0.315)	-0.468 (0.435)
Observations	103	103
Log-Likelihood	-180.224	-177.972

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE 7: Estimated Elasticity Estimates from the Spatial Autocorrelation Models

The dependent variable, Log(Annual Ton-Miles) is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments. The geographic elasticity model is estimated using the elasticity regions defined by Table 4. The weighting matrix used for the spatial autocorrelation model is defined as (see text for details):

$$W_{i,j} = \begin{cases} 0 \text{ if } i = j \\ \frac{1}{1+d_{i,j}} \text{ if } i \neq j \end{cases}$$

where $d_{i,j}$ is the degree of contiguity between pools i and j, i.e. pools i and j are first degree contiguous, and $d_{i,j}=1$ if they share a border, second degree contiguous, $d_{i,j}=2$ if they are separated by 1 pool, etc.

From the Constant Elasticity Specification

Elasticity	-1.607*** (0.551)

From the Geographically Varying Elasticity Specification

For the Upper Mississippi River

	Below Lock 27	Between Locks 27 & 16	Between Locks 16 & 10	Between Locks 10 & 2	Above Lock 2
Elasticity	-1.542*** (0.520)	-1.350** (0.554)	-1.374*** (0.517)	-1.556*** (0.520)	-1.562*** (0.536)

For the Illinois River

	Illinois River Below Lock 5	Illinois River Above Lock 5
Elasticity	-1.558*** (0.511)	-1.592*** (0.523)

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 9: Endogenous Elasticity Estimates for the Upper Mississippi River from the Spatial Autoregressive Model

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Upper Mississippi River system with spatially autocorrelated errors.

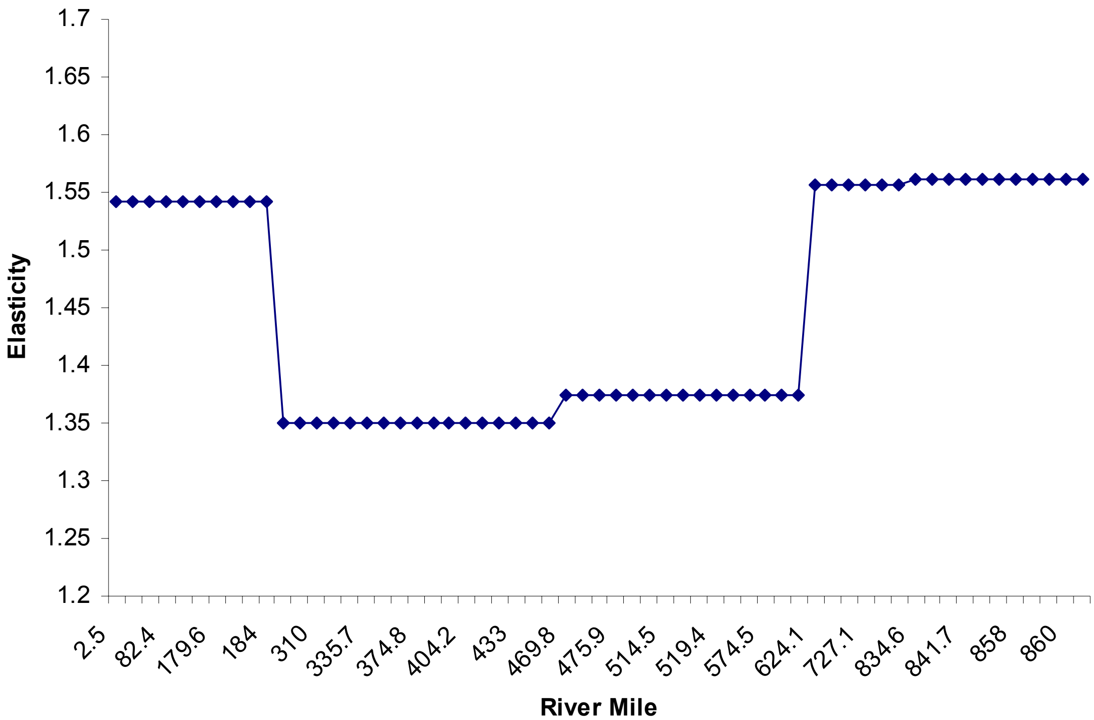
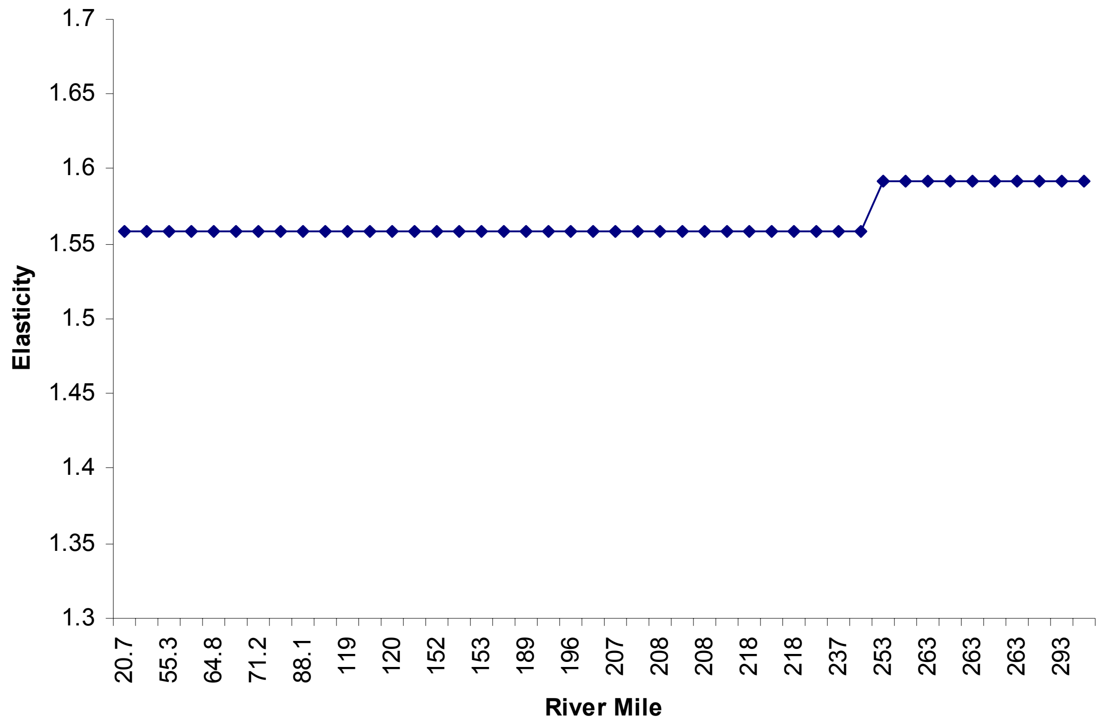


FIGURE 10: Endogenous Elasticity Estimates for the Illinois River from the Spatial Autoregressive Model

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Illinois River system with spatially autocorrelated errors.



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The NETS research program is developing a series of practical tools and techniques that can be used by Corps navigation planners across the country to develop consistent, accurate, useful and comparable information regarding the likely impact of proposed changes to navigation infrastructure or systems.

The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting international and domestic traffic flows and how they may be affected by project improvements.
- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

As these models and other tools are finalized they will be available on the NETS web site:

http://www.corpsnets.us/toolbox.cfm

The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

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The Navigation Economic Technologies Program

November 1, 2005

NETS

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An Overview of the U.S. Inland Waterway System

US Army Corps of Engineers®

IWR Report 05-NETS-R-12

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

For further information on the NETS research program, please contact:

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The NETS program was overseen by Mr. Robert Pietrowsky, Director of the Institute for Water Resources.

November 1, 2005

NETS

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AN OVERVIEW OF THE U.S. INLAND WATERWAY SYSTEM

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IWR Report 05-NETS-R-12

www.corpsnets.us

* All authors are or were students in the Department of Economics at the University of Oregon. The research was conducted under the Navigation Technologies Program (NETS) of the Institute for Water Resources of the Army Corps of Engineers. The research was conducted under the supervision of Wesley W. Wilson, Department of Economics and Institute for Water Resources. All comments and suggestions should be directed to Professor Wesley W. Wilson, Department of Economics, University of Oregon, Eugene, Oregon 97405; (541) 346-4690; and wwilson@uoregon.edu.

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EXECUTIVE SUMMARY

Water transportation is an integral part of the transportation system in the United States. For many commodities and locations, transportation by barge is a more efficient and economically sound form of transporting goods than either rail or truck. The U.S. waterway system is comprised of 12,000 miles of navigable waterway, containing 230 lock sites that manage 275 lock stations. The general purpose of this report is to provide an overview of the inland waterway system both in general and for particular waterways. The waterways described in detail include the Mississippi, the Ohio River Basin, the Gulf Intercoastal Waterway, and the Pacific Coast systems. Specific objectives are to: 1. examine growth patterns for the waterway system as a whole, as well as individual river systems; 2. identify the commodities that specific systems transport and why this makes empirical sense; 3. describe how and why the waterway system works the way it does. The majority of the data used in this survey has been provided by the US Army Corps of Engineers (USACE) or taken from USACE websites.

The data indicate that the primary commodity being transported over the whole of the system is Petroleum and Petroleum products; however, there are substantial differences across waterways and waterway segments. Specifically, Coal and Petroleum account for well over half of the market. Other goods shipped along the waterway system include: chemicals, crude materials, manufactured goods, and food and farm products. Looking at the waterway system from a time dimension, total waterborne commerce has been increasing at a steady rate. This increase is largely a result of increased foreign traffic, as domestic traffic has remained largely stagnant over the twenty years of the survey. Below is a short summary, by system, of major facts that point to the size of the inland waterway system and the primary commodities shipped on each of the largest waterways.

Mississippi River System

- Reflects 9,000 miles of navigable waterway, including about 1800 miles of the Mississippi Main stem and the primary rivers that flow into it, including the Illinois, Missouri, and Ohio rivers.
- 715 million tons shipped in 2001
- 29 locks
- Primary shipments: coal, food and farm products, petroleum, crude materials and chemicals

The Mississippi System is the primary inland waterway system, stretching from Minnesota to Louisiana, and capturing traffic from the Illinois, Missouri and Ohio River systems. The main stem of the Mississippi System dominates the system in terms of traffic movements, so much so that in 2001, some 70.5% of all goods shipped on the waterway were moved along this main stem. This traffic transported via the Mississippi System has increased by about 32.5% since 1982; however, this growth seems to have remained largely stagnant since 1995. As for the composition of this traffic, the primary commodity transported is coal, which totals 26% of all commerce shipped in 2001, followed closely by food and farm products and petroleum.

Ohio River Basin System

- Contains 2,800 miles of navigable waterway
- 275 million tons transported in 1999
- 60 locks
- Primary Shipments: coal, aggregates, petroleum, grains and chemicals

The Ohio River Basin (ORB) system covers approximately 2,800 miles of navigable waterway. The majority of the 275 million tons transported (180 million) are shipped within the basin itself, using the 60 lock and damn facilities maintained by the USACE. The primary commodity shipped through and within the Ohio River Basin is coal, largely due to the large amount of reserves in the region. However, there are also significant amounts of aggregates, petroleum, grains and chemicals shipped on the Ohio River Basin System.

Gulf Intercoastal Waterway System (GIWW)

- Contains 1,109 miles of navigable waterway
- 112 million tons shipped in 2001
- 10 locks
- Primary shipments: petroleum, chemicals, crude materials and coal

The Gulf Intercoastal Waterway has 1,109 miles of navigable waterway on which a significant portion of the United States' commodities are transported. Petroleum is the largest commodity shipped through this system, making up 48.5 % of shipments, followed by chemicals and crude materials accounting for 21% and 18%, respectively. From 1982 to 1988 there was tremendous growth along the Gulf Intercoastal Waterway System with shipments increasing by nearly 42%; however, the growth rate has since stagnated if not decreased.

The Pacific Coast System

- Contains 596 navigable miles
- 50 million tons shipped in 2001
- Eight locks
- Primary shipments: food and farm products, petroleum, crude materials, chemicals, and primary manufactured goods

The Pacific Coast system, which is composed of the Columbia, Snake, and Willamette Rivers, is somewhat different than the other systems discussed both because of its size (only 596 total navigable miles) and because it is not connected to any other waterway system instead flowing directly into the Pacific Ocean. On the Pacific Coast System, agricultural products are the main source of commerce making up 43% of all shipments, while petroleum products are the second largest commodities transported at 19%. The system's growth had shown some growth since 1982, but has seen no significant growth as of late.

1. INTRODUCTION

1.1 GENERAL OVERVIEW

The inland waterway system of the U.S. is vast both in geographic area and tonnages of goods carried. The total network consists of nearly 12,000 navigable miles and offers the benefit of direct access to ocean ports from the nation's interior, often without seasonal difficulties (Great Lakes and Upper Mississippi regions excluded).

Geographically, the system connects all but nine of the fifty states, with a majority of those nine falling within the southwest (Arizona, Colorado, Utah, Wyoming). Figure 1-1 illustrates this waterway network which stretches inward from ocean ports with a majority of the system located within the eastern half of the U.S. In fact, all of the states located east of the Mississippi River have access to this waterway system with several river systems, most notably the Mississippi and Ohio, serving as major arteries. Much like the arteries that supply blood to different parts of the body, these river arteries allow traffic to flow to/from smaller outlying navigable rivers to major port facilities and markets.

The entire system, from ocean ports inward, falls under the jurisdiction of the United States Army Corps of Engineers (USACE), whose responsibility is to operate and maintain all waterway infrastructure needs. These duties can include (but are not limited to) constructing, operating and maintaining waterway dams and locks as well as dredging the waterway channels themselves. Currently, this entails the upkeep of 230 lock sites, incorporating 275 lock chambers; all of which support a wider private infrastructure of over nine thousand commercial waterway facilities. These navigable waterways are also utilized for means other than transportation of goods; namely for municipal and agricultural irrigation, hydropower (dams), recreation and flood control along with general regional development. Additionally, it should be noted that the USACE delineates the entire waterway system into four geographic sections: 1) the Atlantic Coast, 2) the Gulf Coast, Mississippi River System and Antilles, 3) the Great Lakes, and 4) the Pacific Coast, Alaska and Hawaii. For the purpose of this report we focus specifically on the Mississippi River System, the Ohio River Basin, the Gulf Coastal Waterway and the Pacific Coast River System.

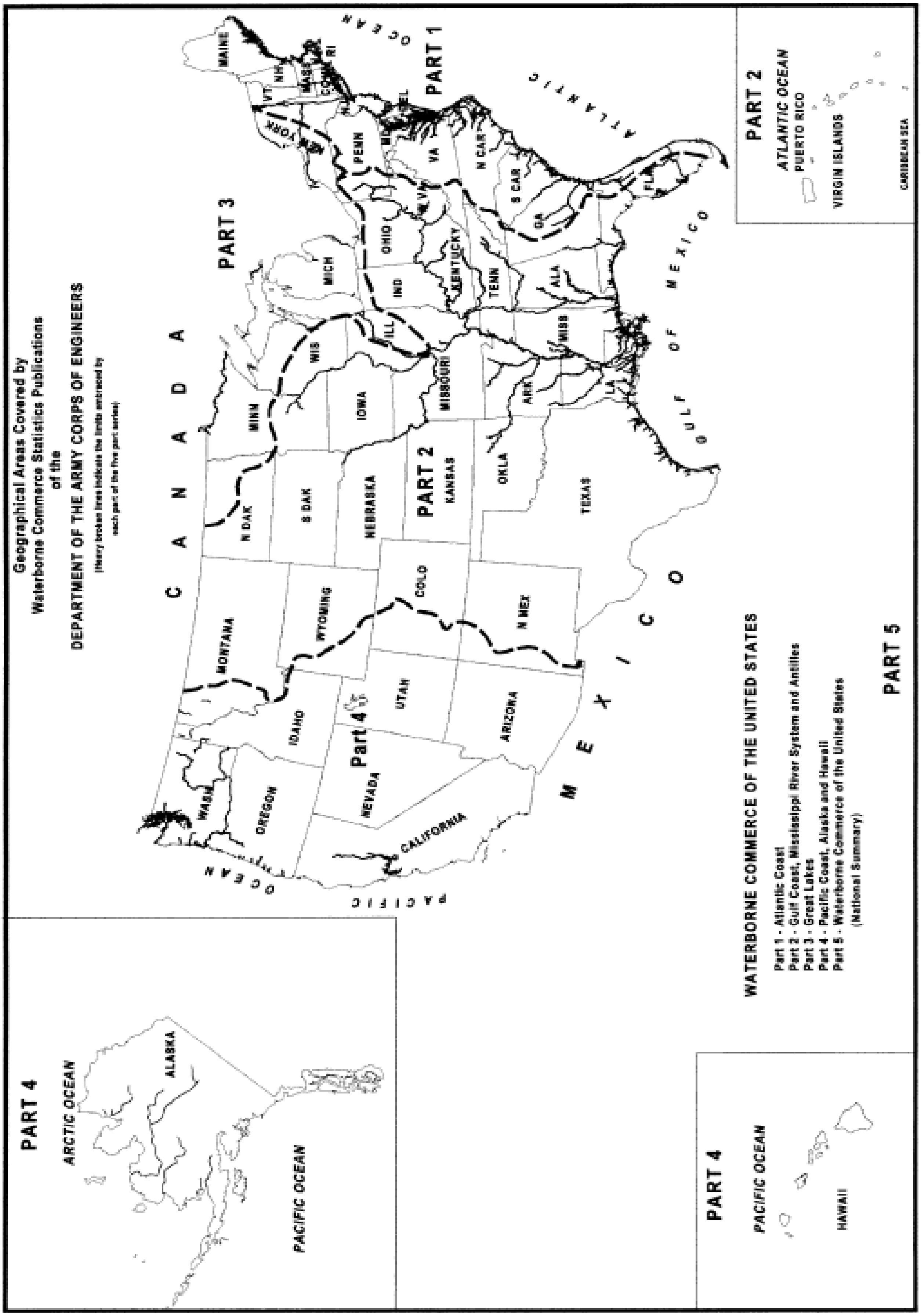


FIGURE 1-1: The Inland Waterway System

1.2 THE DISTRIBUTION OF WATERBORNE ACTIVITIES & FACILITIES

The majority of large ports are located along coastal waters. In fact, of the 189 large port facilities (designated as those handling 250K tons annually) only 25 are considered inland. Although inland facilities comprise only 13% of the total large ports, they account for 47% of the domestic short tons handled and 80% of domestic ton-miles carried.

Port facilities can also be delineated as deep or shallow water. Waterways greater than 12 feet of draft are considered deep, while shallow waterways are usually at 9 feet (except sections of the Snake and Columbia Rivers, which have portions 14 – 15 feet deep, but are still considered shallow waterways). The waterway system as a whole is comprised of 4,869 deep-water facilities and 4,319 shallow water facilities (47% of total). The majority of shallow water ports (55%) are located inland with 97% of the USACE lock sites and 96% of the lock chambers located upon shallow waterways.

The majority of large ports, handling both foreign and domestic traffic, are located along the coastlines. Of the largest 25 ports, all are coastal facilities with only four exceptions: Huntington (WV), Pittsburgh, St. Louis and Duluth-Superior (MN/WI). The first three of these are inland ports, while Duluth-Superior is located on the Great Lakes.

The Mississippi River System flows into the Gulf of Mexico through Louisiana, making both Louisiana and Texas important states for waterborne commerce. Specifically, Louisiana and Texas account for the two largest shares of total waterborne commerce with 496M and 454M short tons, respectively. California follows a distant third with 186M short tons and Pennsylvania and Illinois are fourth and fifth with 125M and 122M short tons, respectively.

Provided below in Table 1-1 are two tables listing the top 100 ports for 2001, based upon total annual tonnage. Column two identifies the ‘type’ of port, with ‘C’ being a coastal facility, while ‘I’ represents an inland facility and an ‘L’ signifies a lakeside port.

Table 1-1 Leading U.S. Ports in 2001

(Millions of Short Tons and Percent Change from 2000)

			Domestic		Foreign		Total[1]	
Rank	**Type[2]**	**Port**	**Tons**	**%**	**Tons**	**%**	**Tons**	**%**
1	C	South Louisiana, LA, Port of	116.9	-1.9	95.7	-1.1	212.6	-1.6
2	C	Houston, TX	64.5	2.9	120.6	-2.7	185.1	-.8
3	C	New York, NY and NJ	70.2	-2.8	67.3	3.6	137.5	.2
4	C	New Orleans, LA	35.3	-7.8	50.3	-2.7	85.6	-4.9
5	C	Beaumont, TX	17.1	6.9	62.0	1.9	79.1	2.9
6	C	Corpus Christi, TX	23.7	-1.4	53.9	-5.9	77.6	-4.6
7	I	Huntington, WV, OH, KY	76.7	-.3	0.0	0	76.7	-.3
8	C	Long Beach, CA	16.1	-7.6	51.6	-1.7	67.6	-3.2
9	C	Texas City, TX	18.1	-10.8	44.1	16.8	62.3	7.2
10	C	Baton Rouge, LA	40.8	-4.1	20.7	-9.0	61.4	-5.8
11	C	Plaquemines, LA, Port of	37.3	-3.9	23.4	12.3	60.7	1.7
12	I	Pittsburgh, PA	53.0	-1.7	0.0	0	53.0	-1.7
13	C	Lake Charles, LA	20.9	2.2	31.9	-1.9	52.8	-.3
14	C	Los Angeles, CA	6.4	6.0	45.0	6.9	51.4	6.8
15	C	Valdez, AK	51.0	9.8	0.0	-99.8	51.0	6.0
16	C	Mobile, AL	20.1	-16.9	28.0	-4.9	48.1	-10.3
17	C	Philadelphia, PA	13.4	-4.5	32.9	23.1	46.4	13.6
18	C	Tampa, Fl	28.3	-10.5	17.4	17.9	45.8	-1.4
19	C	Baltimore, MD	16.7	15.0	25.4	-3.6	42.1	3.0
20	L	Duluth-Superior, MN and WI	26.5	-5.8	13.3	-1.7	39.8	-4.5
21	C	Norfolk Harbor, VA	10.3	-1.6	27.0	-15.2	37.3	-11.9
22	I	St. Louis, MO and IL	34.4	3.3	0.0	0	34.4	3.3
23	C	Portland, OR	14.3	-12.4	17.0	-5.3	31.3	-8.7
24	C	Freeport, TX	5.2	-6.3	24.9	6.5	30.1	4.0
25	C	Pascagoula, MS	11.1	5.8	18.5	2.1	29.5	3.5
26	C	Portland, ME	2.0	-12.6	26.4	.0	28.5	-1.1
27	C	Charleston, SC	6.1	35.2	17.1	3.5	23.3	10.3
28	C	Port Arthur, TX	7.7	-9.5	15.1	25.6	22.8	11.1
29	L	Chicago, IL	19.3	-3.7	2.6	-31.5	22.0	-8.2
30	C	Port Everglades, FL	12.3	-7.5	9.6	4.4	21.9	-2.6
31	C	Paulsboro, NJ	8.3	-9.2	12.9	-18.2	21.3	-14.9
32	C	Richmond, CA	11.2	23.5	10.0	-2.9	21.2	9.5
33	C	Boston, MA	8.2	-2.8	12.4	.5	20.6	-.8
34	C	Seattle, WA	5.6	-35.5	14.9	-3.3	20.5	-14.9
35	C	Tacoma, WA	8.1	-1.5	12.4	-11.7	20.5	-7.9
36	C	Savannah, GA	2.5	-10.1	16.9	.9	19.4	-.6
37	C	Marcus Hook, PA	10.9	22.6	8.2	-33.0	19.1	-9.7
38	C	Jacksonville, FL	8.9	-12.9	8.9	-6.1	17.8	-9.6
39	L	Detroit, MI	12.3	2.3	4.7	-10.9	17.0	-1.8
40	I	Memphis, TN	16.9	-7.5	0.0	0	16.9	-7.5
41	C	Anacortes, EA	14.8	-7.4	2.0	-2.7	16.8	-6.9
42	C	Honolulu, HI	11.8	7.6	4.8	5.1	16.6	6.8
43	I	Cincinnati, OH	14.1	-1.7	0.0	0	14.1	-1.7
44	C	Newport News, VA	7.2	.3	6.7	.5	13.9	.4
45	L	Indiana Harbor, IN	12.8	-17.2	0.7	9.5	13.6	-16.1
46	C	San Juan, PR	7.6	-2.4	5.2	-14.0	12.8	-7.5
47	C	Oakland, CA	1.6	-17.3	10.7	4.2	12.3	.9
48	L	Two Harbors, MN	11.9	-9.1	0.0	0	11.9	-9.1
49	L	Cleveland, OH	9.1	-23.4	2.7	10.4	11.9	-17.6
50	L	Ashtabula, OH	5.1	-.6	5.8	-18.9	10.9	-11.3

Leading U.S. Ports in 2001 -- continued
(Millions of Short Tons and Percent Change from 2000)

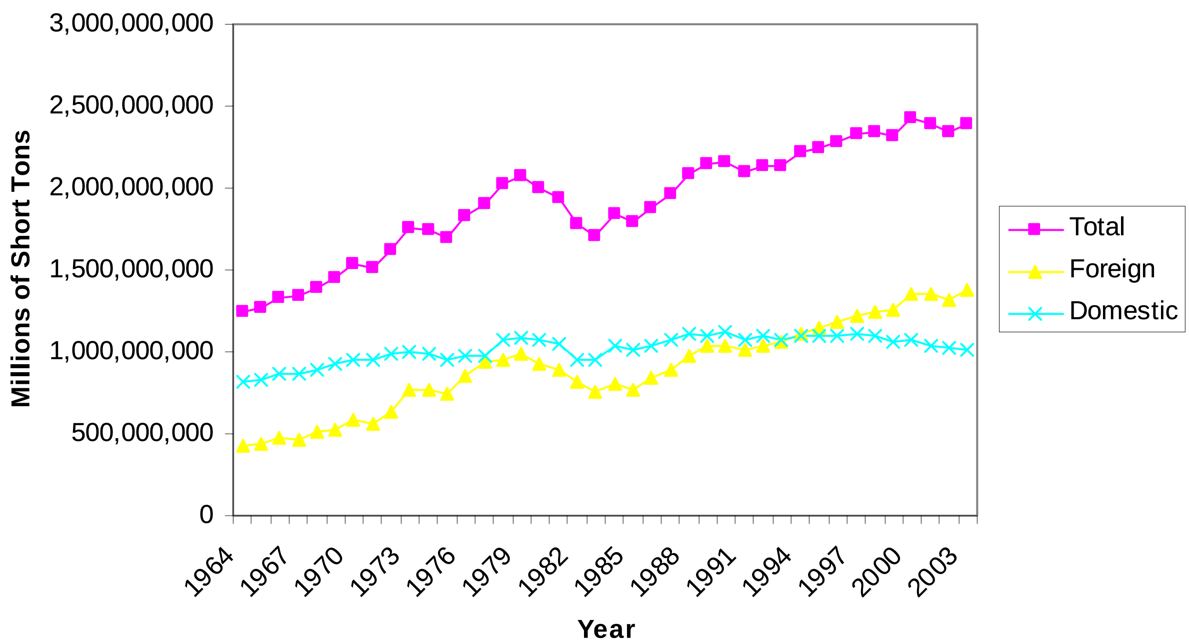
Rank	Type[2]	Port	Domestic Tons	Domestic %	Foreign Tons	Foreign %	Total[1] Tons	Total[1] %
51	L	Toledo, OH	4.5	-23.7	6.0	-18.7	10.5	-20.9
52	L	Conneaut, OH	3.8	-30.6	6.6	31.0	10.5	-1.1
53	C	New Haven, CT	6.8	-1.8	3.1	-16.3	9.9	-6.9
54	L	Presque Isle, MI	7.6	-7.0	1.8	-27.4	9.5	-11.8
55	I	Louisville, KY	9.1	-.9	0.0	0	9.1	-.9
56	C	Matagorda Ship Channel, TX	2.6	-24.4	6.5	-9.0	9.1	-13.9
57	C	Galveston, TX	5.1	41.1	3.9	-41.9	9.0	1.8
58	C	Providence, RI	5.7	1.7	3.3	1.9	9.0	1.8
59	L	Gary, IN	8.5	-9.5	0.4	29.2	8.9	-8.3
60	L	Burns Waterway Harbor, IN	6.9	-5.3	1.9	-10.9	8.7	-6.5
61	C	New Castle, DE	5.2	-4.3	3.4	8.2	8.6	.3
62	C	Miami, FL	1.1	-22.0	7.4	3.0	8.5	-1.1
63	L	Calcite, MI	7.3	2.2	1.1	-23.0	8.3	-1.9
64	L	Stoneport, MI	7.9	4.6	0.2	-33.0	8.1	3.2
65	L	Lorain, OH	7.6	-45.6	0.3	9.4	7.9	-44.5
66	C	Albany, NY	5.6	4.3	1.7	114.1	7.3	18.6
67	C	Vancouver, WA	2.3	-31.5	4.8	9.7	7.0	-8.0
68	L	Escanaba, MI	6.9	-19.7	0.0	0	7.0	-19.3
69	C	Kalama, WA	1.2	10.7	5.4	15.6	6.6	14.7
70	C	Wilmington, DE	1.3	16.5	5.1	26.1	6.4	24.1
71	C	Nikishka, AK	3.3	64.0	3.0	-1.5	6.4	-24.7
72	L	Port Inland, MI	5.2	4.1	1.1	108.9	6.3	14.2
73	C	Wilmington, NC	3.0	-18.6	3.2	5.5	6.2	-7.6
74	C	Barbers Point, Oahu, HI	3.9	11.6	2.2	-33.2	6.1	-10.3
75	C	Camden-Gloucester, NJ	2.5	3.6	2.6	-4.8	5.1	-.9
76	I	Nashville, TN	4.8	7.1	0.0	0	4.8	7.1
77	L	St. Clair, MI	4.8	-13.2	0.0	-100.0	4.8	-13.2
78	I	Vicksburg, MS	4.7	-4.7	0.0	0	4.7	-4.7
79	C	Victoria, TX	4.7	-7.3	0.0	0	4.7	-7.3
80	I	St. Paul, MN	4.7	-11.2	0.0	0	4.7	-11.2
81	L	Sandusky, OH	1.5	100.9	3.2	9.1	4.6	27.6
82	C	Bridgeport, CT	3.4	3.2	1.2	22.3	4.6	7.7
83	C	Portsmouth, NH	0.6	-30.4	3.9	6.5	4.4	-.4
84	C	Port Canaveral, FL	1.5	6.2	2.9	1.5	4.4	3.1
85	L	Silver Bay, MN	4.3	-20.0	0.0	-100.0	4.3	-20.2
86	I	Kansas City, MO	4.3	11.9	0.0	0	4.3	11.9
87	C	Brownsville, TX	1.8	29.8	2.3	22.3	4.1	25.5
88	C	Chester, PA	0.3	-3.6	3.7	104.4	4.0	86.8
89	L	Marine City, MI	3.9	.4	0.0	-85.6	3.9	-2.3
90	C	Port Manatee, FL	1.4	-22.7	2.4	-2.6	3.8	-11.2
91	C	Kahului, Maui, HI	3.5	1.8	0.2	0	3.7	6.3
92	C	Longview, WA	0.5	-49.7	3.1	-1.7	3.6	-12.7
93	C	Palm Beach, FL	2.2	30.1	1.3	4.1	3.5	19.3
94	C	Fall River, MA	2.8	2.3	0.6	-11.6	3.4	-.6
95	L	Milwaukee, WI	1.7	-25.3	1.6	34.0	3.4	-4.7
96	C	Penn Manor, PA	0.1	-18.0	3.2	-5.4	3.3	-5.8
97	L	Port Dolomite, MI	2.9	-3.0	0.4	79.4	3.3	2.8
98	L	Alpena, MI	3.1	-3.2	0.1	-18.7	3.3	-4.0
99	C	Ponce, PR	0.1	-41.2	3.1	49.6	3.2	42.6
100	C	Morehead City, NC	1.1	-27.6	2.1	-28.2	3.1	-28.0

Source: The U.S. Waterway System-Transportation Facts, U.S. Army Corps of Engineers, (2002)

1.3 TOTAL WATERBORNE COMMERCE & PRINCIPAL COMMODITIES SHIPPED

Waterborne commerce tonnages have increased over time. In fact, as shown in Figure 1-2, total tonnages have increased steadily since 1962. Figure 1-2 also shows that this increase in total tonnages shipped has been largely the result of increased foreign traffic, as opposed to domestic traffic.

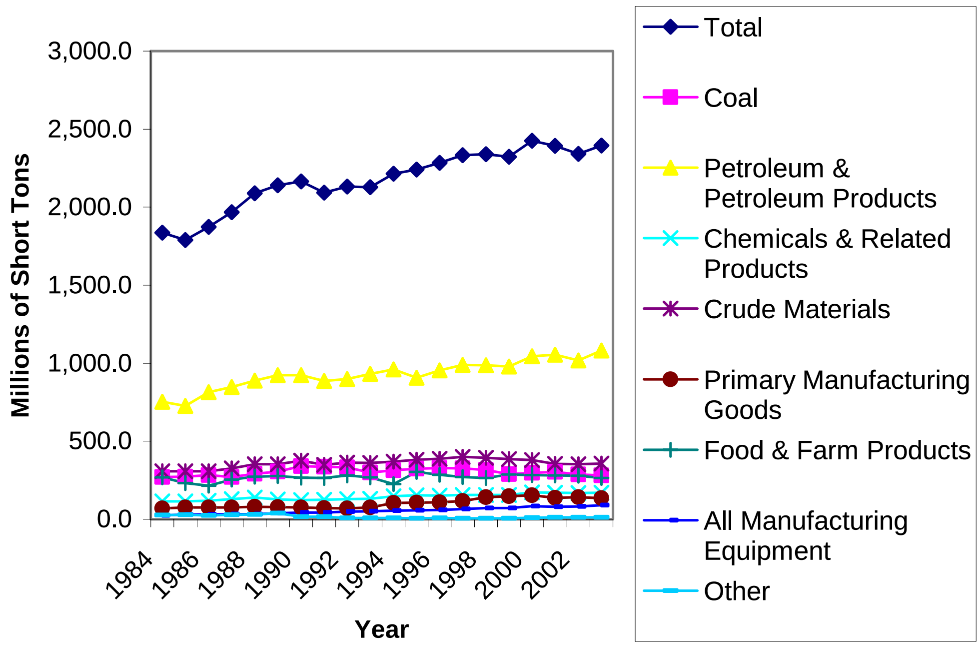
FIGURE 1-2: Total Waterborne Commerce of the U.S., 1964-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 1-2*

By commodity, Figure 1-3 and Table 1-2 show that the dominant product carried on the waterway system is petroleum and its related products which account for 750 to 1000M tons per year. Crude materials at approximately 350M tons and coal with approximately 300M tons round out the top three commodities carried on the waterway system.

FIGURE 1-3: Total Waterborne Commerce by Commodity, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 1-3*

TABLE 1-2: Total Waterborne Commerce by Commodity, 1984-2003 (millions of short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	1,836.0	1,788.4	1,874.4	1,967.5	2088.0	2140.4	2163.9	2092.1	2132.1	2128.2
Coal	271.8	273.9	283.9	271.3	292.2	304.8	339.9	336.8	332.2	300.4
Petroleum & Petroleum Products	753.5	726.4	815.6	847.7	887.7	922.7	923.5	886	899.6	930.6
Chemicals & Related Products	115.1	114.3	118.6	129	138.8	127.8	123.8	125.1	128.7	131.6
Crude Materials	307.1	307.1	308.4	327.1	352	353.2	374.9	348.9	364	360.6
Primary Manufacturing Goods	69.3	76.9	76	76.5	79.5	77.8	76	71.8	70.1	76.8
Food & Farm Products	268.3	231	215.2	254.1	273.4	276	267.5	263.9	280.4	269.3
All Manufacturing Equipment	25.1	29.8	31.4	33.6	33.8	38.4	42.2	43.6	49	51.1
Other	25.8	29.1	25.5	28.2	30.5	39.7	16.5	16	8	7.9
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	2214.8	2240.4	2284.1	2333.1	2339.5	2322.6	2424.6	2393.3	2340.3	2394.3
Coal	314.1	324.5	328.7	326.0	316.1	289.2	297.0	303.3	286.9	281.2
Petroleum & Petroleum Products	961.3	907.1	954.4	988.2	987.4	979.1	1043.9	1055.3	1017.9	1080.5
Chemicals & Related Products	146.9	152.9	152.3	156.6	156.5	155.7	172.4	169.7	167.6	171.3
Crude Materials	369.3	381.7	388.7	400.9	394.3	386.6	380.3	354.0	352.0	358.0
Primary Manufacturing Goods	105.0	106.3	108.9	117.0	141.0	147.4	153.0	137.1	140.8	134.7
Food & Farm Products	225.8	303.2	284.9	271.7	265.7	287.9	283.3	281.9	280.0	265.7
All Manufacturing Equipment	54.9	57.8	59.0	66.1	71.8	71.5	83.6	80.3	81.9	90.0
Other	7.3	6.9	7.2	6.6	6.6	5.2	11.1	11.7	13.2	12.8

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 1-5*

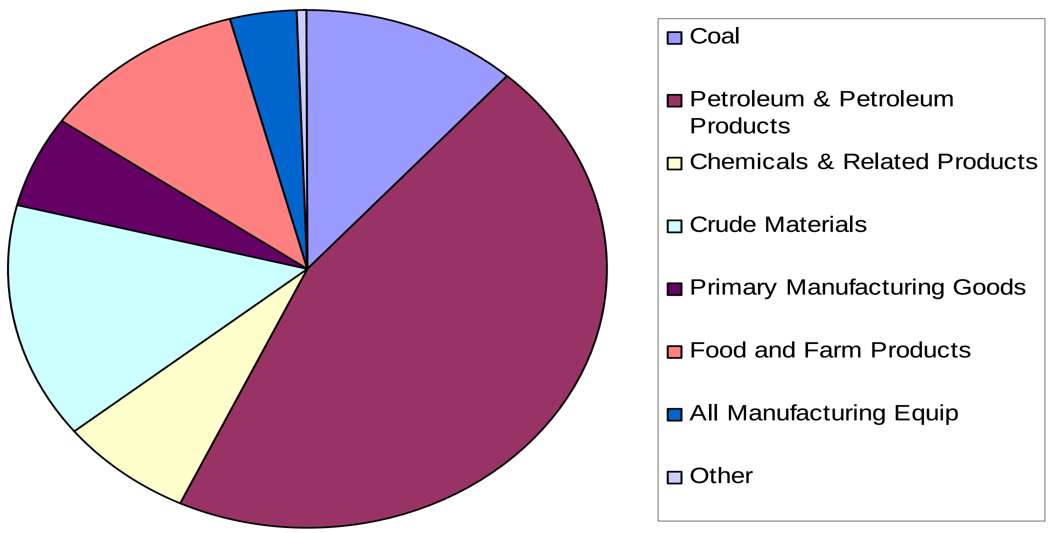
From an international perspective, Table 1-3 and Figures 1-4, 1-5 and 1-6 show tonnages of commodities shipped as either foreign or domestic based. Foreign commodity traffic is dominated by petroleum, food and farm products and crude materials third. Alternatively, domestic traffic consists largely of petroleum, coal and crude materials.

TABLE 1-3: Principle Commodities in Waterborne Commerce 2002-2003 (millions of short tons)

	2002	2003	% Change
Total Commerce	2,340.30	2,394.30	2.3
Coal	286.9	281.2	-2
Petroleum & Petroleum Products	1,017.90	1,080.50	6.2
Chemicals & Related Products	167.6	171.3	2.2
Crude Materials	352	358	1.7
Primary Manufacturing Goods	140.8	134.7	-4.4
Food and Farm Products	280	265.7	-5.1
All Manufacturing Equip	81.9	90	10
Other	13.2	12.8	-2.7
Foreign Commerce	1,319.30	1,378.10	4.5
Coal	59.9	67.6	12.9
Petroleum & Petroleum Products	669.2	719.7	7.5
Chemicals & Related Products	94.5	95.6	1.1
Crude Materials	137.2	146.4	6.7
Primary Manufacturing Goods	98.4	93	-5.5
Food and Farm Products	182.5	174.8	-4.2
All Manufacturing Equip	67.3	71.3	6
Other	10.2	9.6	-5.8
Domestic Commerce	1,021.00	1,016.10	-0.5
Coal	227	213.5	-5.9
Petroleum & Petroleum Products	348.7	360.8	3.5
Chemicals & Related Products	73.1	75.7	3.6
Crude Materials	214.7	211.6	-1.5
Primary Manufacturing Goods	42.4	41.7	-1.7
Food and Farm Products	97.6	90.9	-6.8
All Manufacturing Equip	14.6	18.7	28.4
Other	3	3.2	8.3

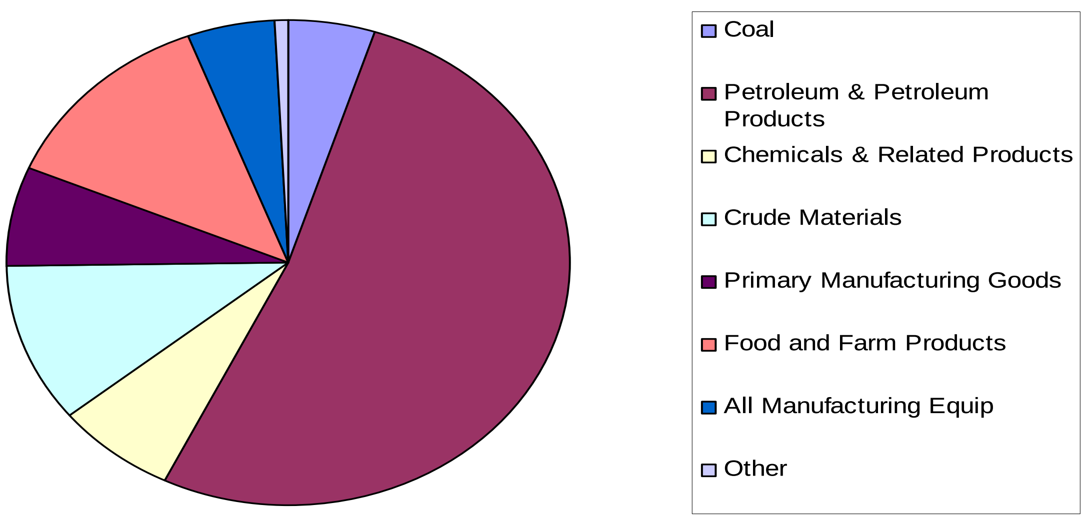
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 2-4*

FIGURE 1-4: Principle Commodities in Waterborne Commerce, 2003 (Total)



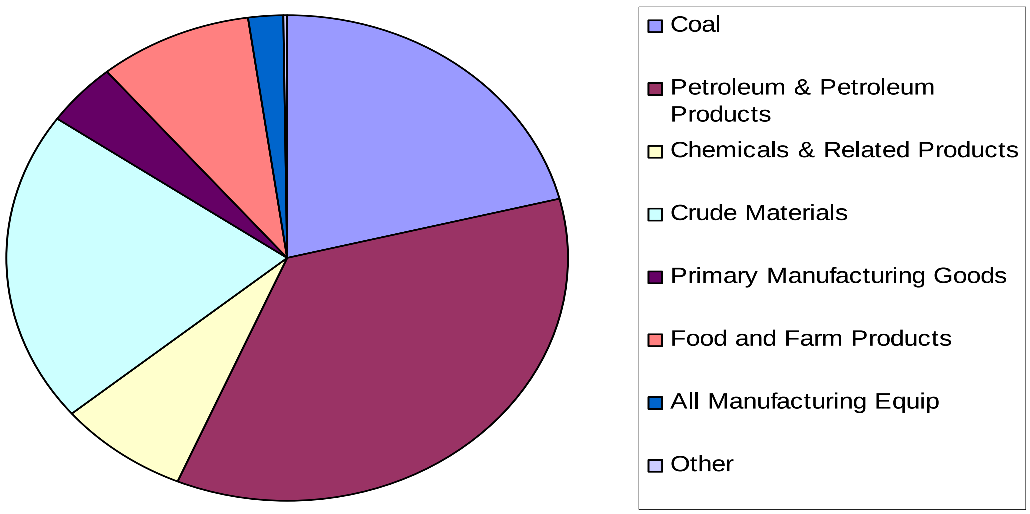
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 2-2*

FIGURE 1-5: Principle Commodities in Waterborne Commerce, 2003 (Foreign)



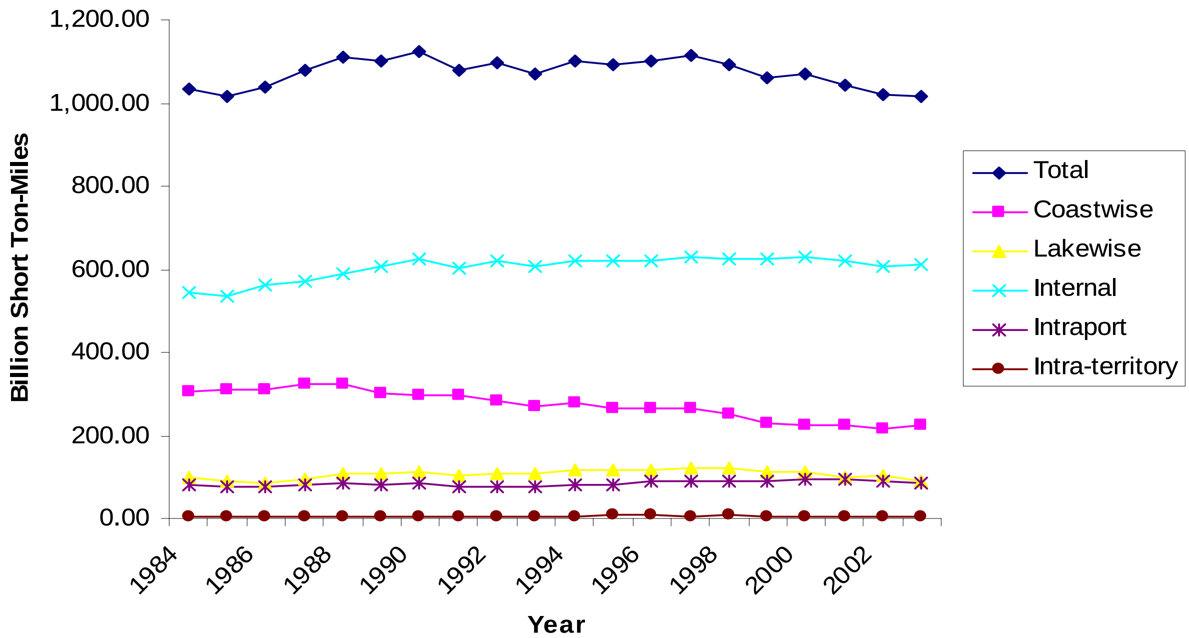
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 2-2*

FIGURE 1-6: Principle Commodities in Waterborne Commerce, 2003 (Domestic)



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 2-2*

FIGURE 1-7: Domestic Waterborne Commerce, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 1-6*

Broken down by type of traffic, domestic traffic has seen intraport and lakewise shipments remain steady with internal domestic commerce slightly increasing over time and coastwise domestic traffic decreasing as seen in Figure 1-7 and Table 1-4.

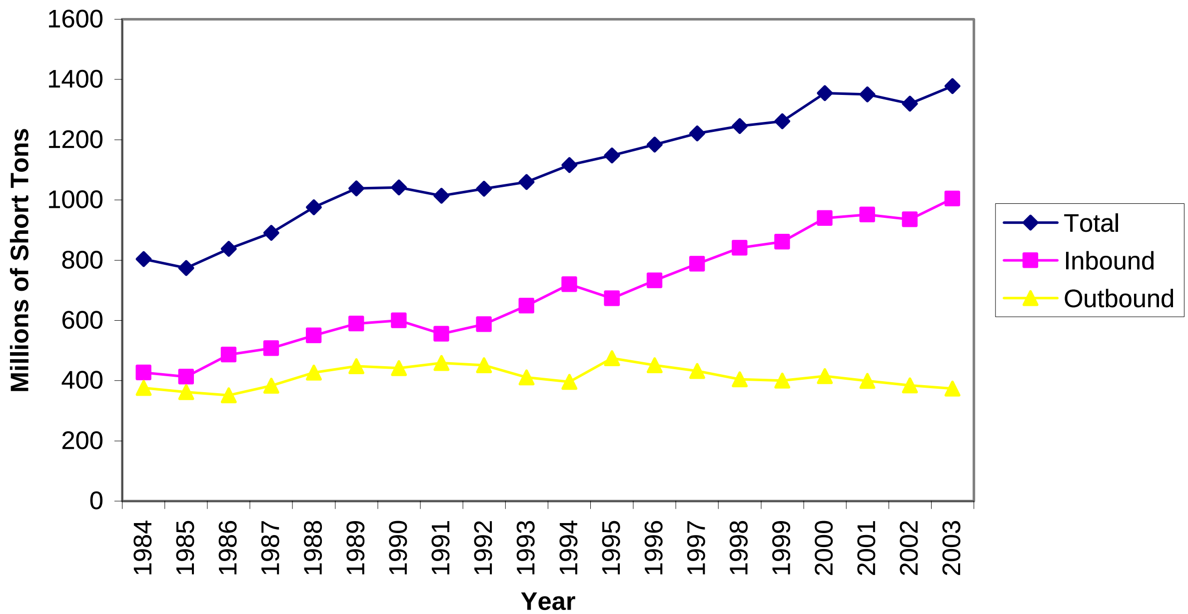
TABLE 1-4: Domestic Waterborne Commerce, 1984-2003 (billion short ton-miles)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	1,032.70	1,014.10	1,037.20	1,076.50	1,111.80	1,102.50	1,122.30	1,078.60	1,094.60	1,068.20
Coastwise	307.7	309.8	308	323.5	325.2	302	298.6	294.5	285.1	271.7
Lakewise	98	92	87.4	96.5	109.7	109.1	110.2	103.4	107.4	109.9
Internal	542.5	534.7	560.5	569.8	588.1	606	622.6	600.4	621	607.3
Intraport	81.1	74.3	77.4	82	83.7	80.2	86.4	75.6	76.8	74.4
Intra-territory	3.4	3.4	4	4.7	5.1	5.2	4.5	4.6	4.2	5
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	1,099.00	1,093.00	1,100.70	1,112.50	1,094.10	1,061.80	1,069.80	1,042.50	1,021.00	1,016.10
Coastwise	277	266.6	267.4	263.1	249.6	228.8	226.9	223.6	216.4	223.5
Lakewise	114.8	116.1	114.9	122.7	122.2	113.9	114.4	100	101.5	89.8
Internal	618.4	620.3	622.1	630.6	625	624.6	628.4	619.8	608	609.6
Intraport	82.9	83.1	89	89.8	90.1	88.7	94.6	93.2	90	86.9
Intra-territory	5.9	6.9	7.3	6.3	7.2	5.9	5.5	5.9	5.1	6.4

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 1-8*

Foreign waterborne commerce, displayed in figure 1-7 and table 1-6 has grown over time, with the primary growth coming from inbound traffic, which has shown steady gains since 1984.

FIGURE 1-8: Foreign Waterborne Commerce Inbound and Outbound Traffic, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 1-4*

TABLE 1-5: Foreign Waterborne Commerce Inbound and Outbound Traffic, 1984-2003 (millions of short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	803.3	774.3	837.2	891	976.2	1,037.90	1,041.60	1,013.60	1,037.50	1,060.00
Inbound	427.1	412.7	486.1	507.7	549.9	589.5	600	555.4	586.7	648.8
Outbound	376.2	361.6	351.2	383.3	426.3	448.4	441.6	458.2	450.8	411.3
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	1,115.70	1,147.40	1,183.40	1,220.60	1,245.40	1,260.80	1,354.80	1,350.80	1,319.30	1,378.10
Inbound	719.5	672.7	732.6	788.3	840.7	860.8	939.7	951.8	934.9	1,004.80
Outbound	396.2	474.7	450.8	432.3	404.7	400	415	399	384.3	373.3

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 1-6*

2. COMMODITY FLOWS OF THE U.S. WATERWAY SYSTEM

2.1 INTRODUCTION

Relative to other modes of transportation, water-based transportation garnishes a relatively small portion of total commodities carried. Specifically, according to the 1997 Economic Census, water moved 9.8% of total ton-miles of national transportation needs. This was based upon 5.1% of total ton-miles having a relative value of 1.1% for all goods transported. The dominant modes were truck and rail, each transporting nearly identical portions of total ton-miles (38.5%). Trucks, however, captured 70% of both total tons and value transported.

However, the role of waterways is critical, especially considering the prevalence of multi-mode shipments. Approximately 6% of total tons, 10% of ton-miles and 18% of combined value is shipped via multi-mode transports. But, of these shipments, water travel was a component in over half (54.5%) of these transactions. Water travel was also involved with 50% of total tons carried. As such, water-based travel proves a more integral component of the U.S. transportation system than a casual glance would suggest.

Multi-mode transportation seemed to be getting more important over the years 1993 – 1997, when multi-mode transportation increased 6.8%. Interestingly, truck and water (T&W) decreased 14.4%, but was nearly offset by an increase of 10.5% in rail and water (R&W) shipments. It should be noted that 70% of ton-mile shipments for T&W are greater than 100K pounds. For R&W, shipments over 100K pounds accounted for 99.7% of all ton-miles shipped, which is nearly identical for that of shallow draft (single mode).

When focusing solely upon shallow draft (i.e., inland waterways), single mode shipments accounted for 8.5% of national ton-miles with an average distance traveled of 253 miles. These shallow draft shipments increased by 32% in value shipped over the years 1993 – 1997, 14% in total tons hauled and 15% in ton-miles.

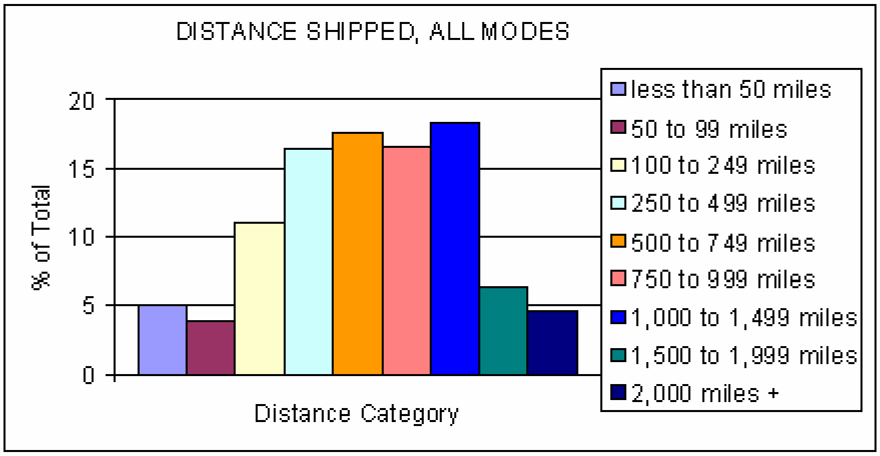


Figure 2-1

Source: 1997 Commodity Flow Survey, based on the 1997 Economic Transportation Survey

Stepping back to ascertain the transportation picture in its entirety, a few graphs will be in order. To start, the Figure 2-1 depicts the distribution of all transported goods over select distances, inclusive of all modes. As can be readily seen, the distribution is relatively evenly cast over distances of 250 to 1,500 miles. However, shallow draft distances are considerably longer as seen in Figure 2-2.

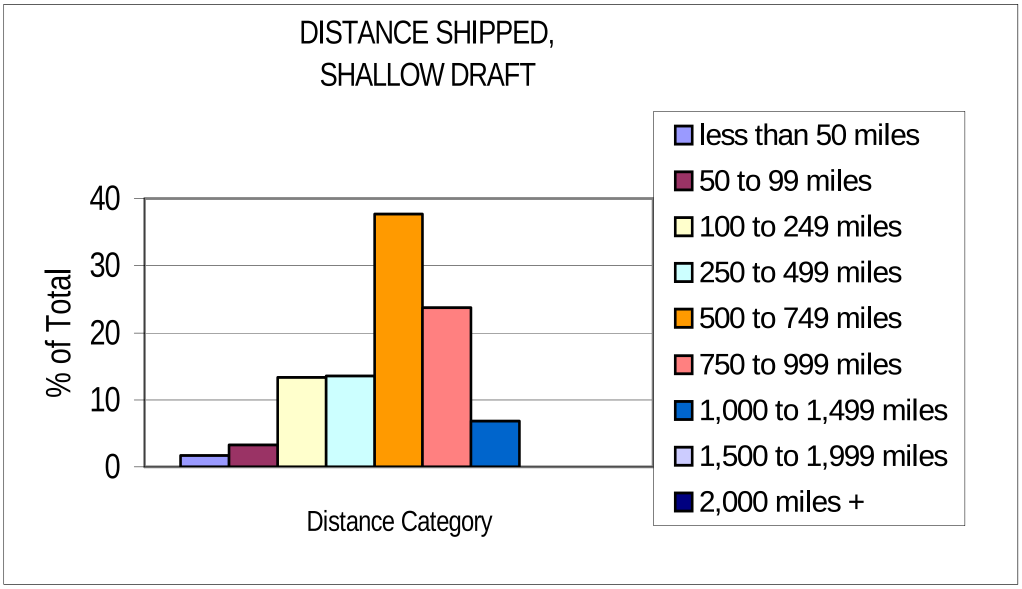


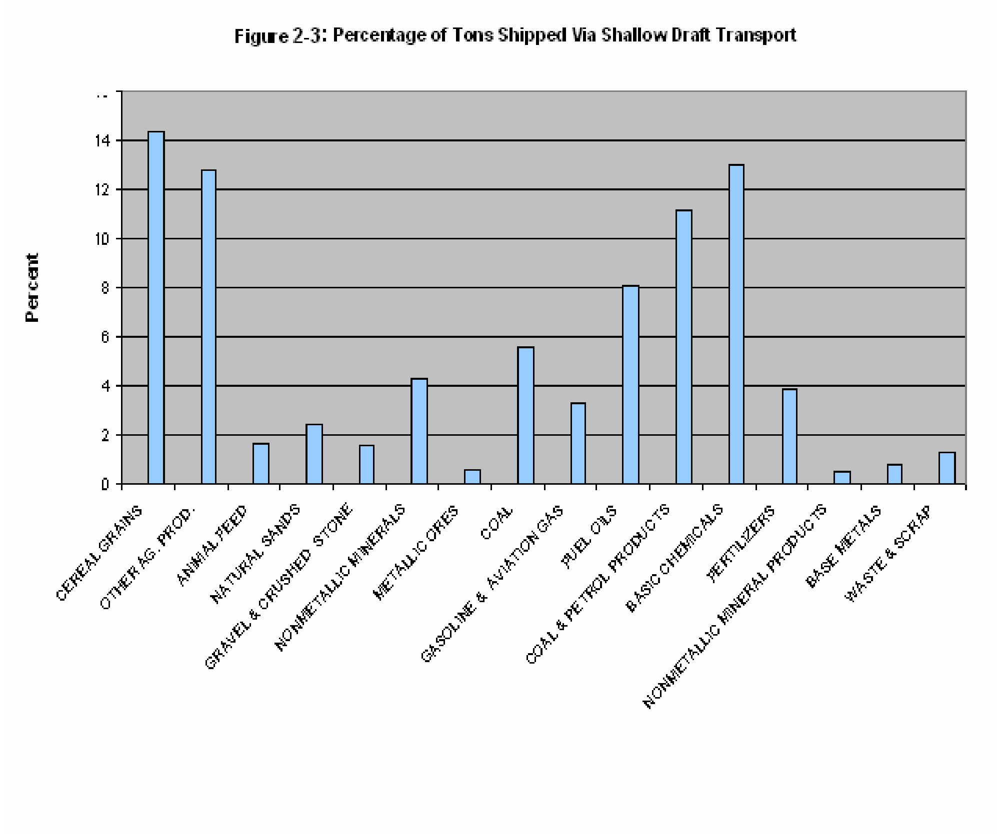
Figure 2-2
Source: 1997 Commodity Flow Survey, based on the 1997 Economic Transportation Survey

Additionally, when taking into account multi-mode distances, there appear to be distinct differences between the distributions of rail and water versus that of truck and water. Rail and water (R&W) distances were primarily over longer ranges (750 – 1500mi.), while truck and water trips were shorter in duration, evenly distributed from 250 to 1000 miles. Only 12% of distances were of 2000 miles or greater for T&W.

2.2 RELEVANT SHALLOW DRAFT COMMODITIES

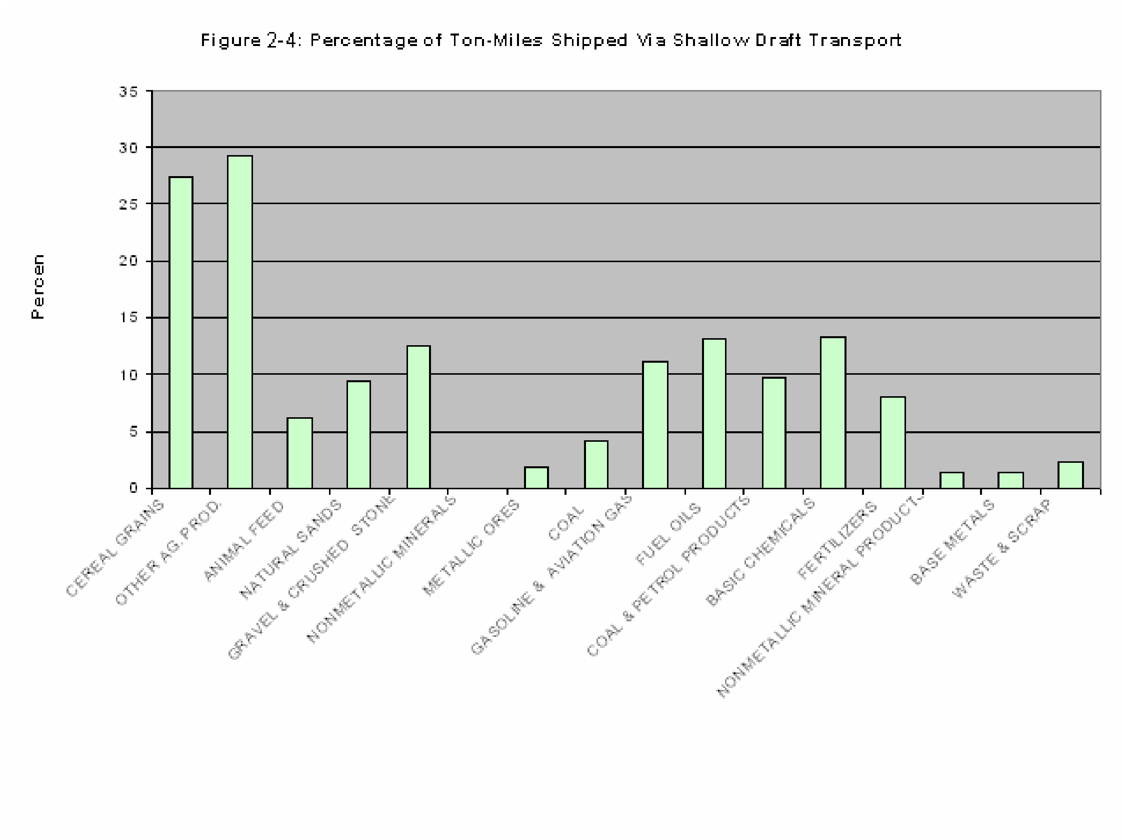
Of the 43 Standard Classification of Transported Goods (SCTG) commodity classifications listed within the 1997 Economic Census, there are 16 relevant groupings for shallow draft transportation. These, not surprisingly, are all bulk commodities. The emphasis upon bulk transportation reflects the inland waterway's natural comparative advantage in hauling these large-scale commodities.

Figure 2-3 depicts each of the sixteen significant commodities evaluated with relation to the percentage of tons carried by shallow draft transport as compared to other modes shipping that particular good. As can be seen, all commodities were under fifteen percent, with only five above 8%. The remaining eleven commodities all exhibited low percentages of relative transport totals. As should be expected, coal, petroleum products and agricultural products all were amongst those commodities with relatively higher total carrying ratios.



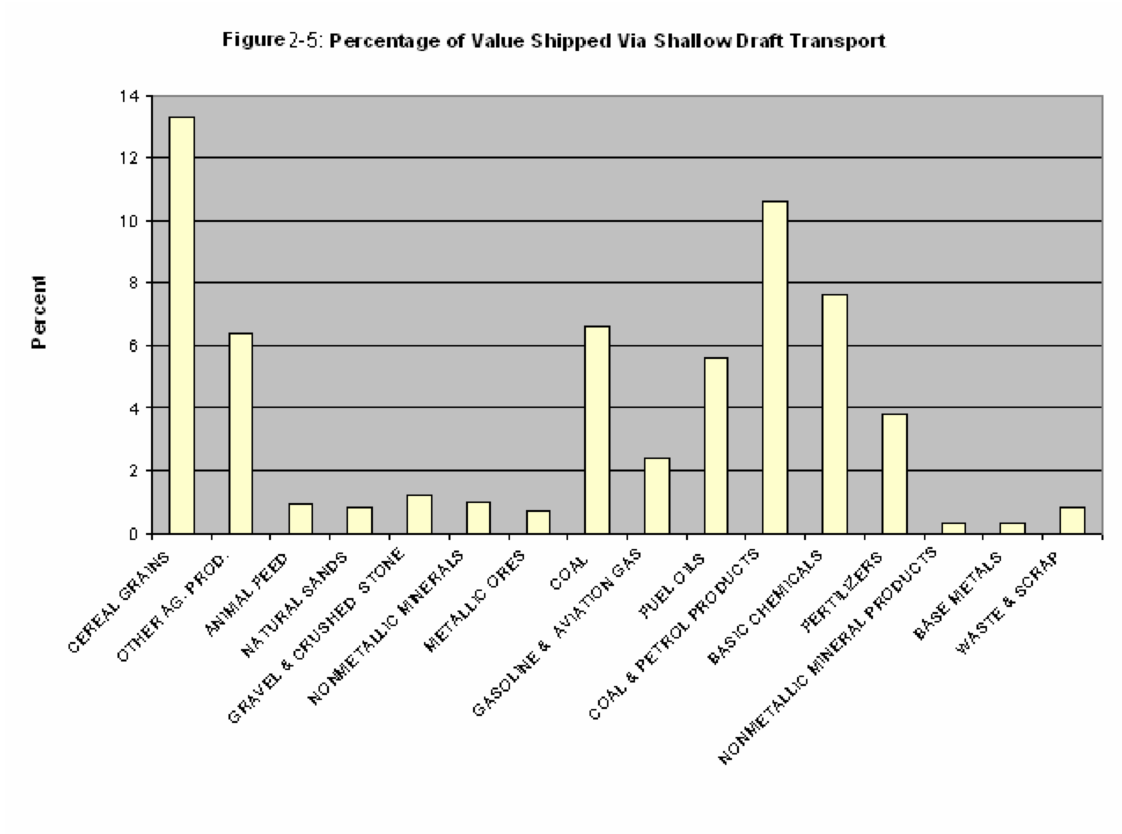
Source: 1997 Commodity Flow Survey, based on the 1997 Economic Transportation Survey

Figure 2-4 shows the percentage of ton-mile shipped via shallow draft transportation. In terms of ton-miles, eleven primary water-borne commodities (coal and petroleum, basic chemicals) showed percentages of approximately 10% or greater. Of particular interest are the two similar commodities: Cereal Grains (SCTG 2) and Other Ag. Products (SCTG 3). Both were significantly higher than the other commodities, with percentages of 27.4 and 29.3, respectively. Others, namely Nonmetallic Minerals (SCTG 13) were non-tractable due to “high variability or other reasons” within the data, as stated in the 1997 Transportation Census.



Source: 1997 Commodity Flow Survey, based on the 1997 Economic Transportation Survey

Figure 2-5 paints a similar picture to the previous two graphs, this time in terms of the value the product transported. Again, agricultural products are the dominant commodities. Cereal Grains in particular mimicked earlier percentages in both tons and ton-miles, here showing that over 13% of total value was transported via internal waterways. SCTG 19 (Coal and Petroleum Products) along with Coal (SCTG 15) and Basic Chemicals (SCTG 20) additionally exhibited percentages in excess of 6.5%.



Source: 1997 Commodity Flow Survey, based on the 1997 Economic Transportation Survey

In terms of the average distance carried, the commodities can be categorized into three groupings. Specifically, three agricultural commodities (Cereal Grains, Other Ag. Products, Animal Feed) made up the first group with an average distance well over 800 miles. The second class, consisting of mineral-based goods, were carried over more moderate distances (400- 800 miles, on average) and consisted of the ‘mineral group’ (i.e., Nonmetallic Minerals, Metallic Ores, Base Metals, Waste and Scrap) along with Basic Chemicals (400 mile avg.). The final grouping is that of commodities with smaller average transport distances (sub-400 miles) or simply insufficient data to correctly ascertain (Fuel Oils, for example). The average distance traveled for each of these commodities is shown below in Figure 2-6.

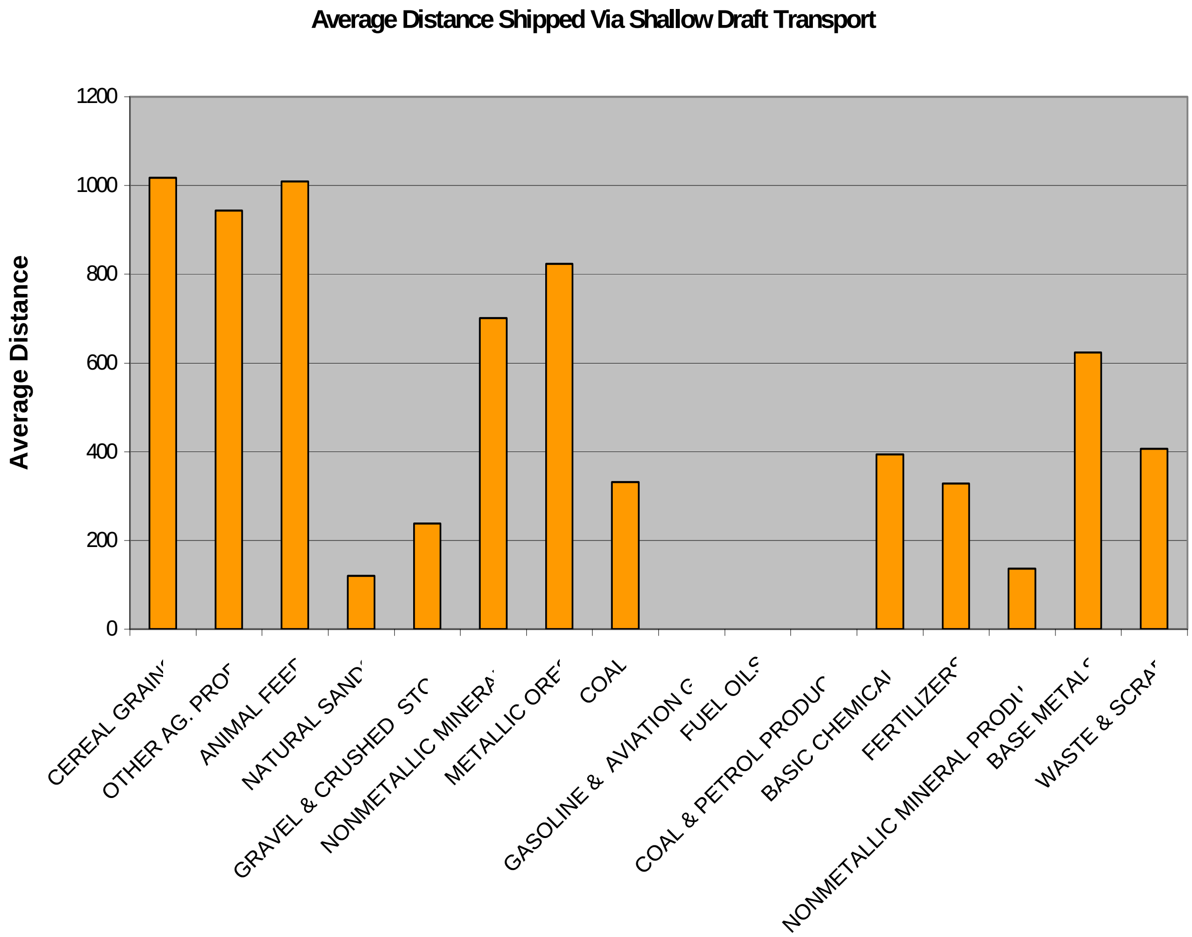


Figure 2-6

Source: 1997 Commodity Flow Survey, based on the 1997 Economic Transportation Survey

THE MISSISSIPPI RIVER SYSTEM

3.1 INTRODUCTION

Stretching from the upper reaches of Minnesota to the Gulf of Mexico and dropping from an elevation of 1475 feet above sea level, the Mississippi is the second longest river in North America (only the Missouri is longer). As part of a navigable waterway system, it begins in Minneapolis and flows for over 1800 miles as it joins other waterway arteries. Specifically, south of Minneapolis, the navigable portion of the Mississippi later couples with both the Missouri and Illinois rivers near St. Louis. Flowing further southward, in proximity to Cairo, Illinois, it is wedded with another major waterway discussed above, namely that of the Ohio and its adjoining tributaries. On its pathway to the Gulf, the enlarged Mississippi additionally incorporates the Arkansas and Ouachita rivers as it approaches the end of its journey. Thus, the Mississippi River itself is one of many interconnected waterways which are part of a larger embodiment, designated the Mississippi River Main Stem.

Considering the Mississippi River itself, the river is often divided into two sections: the Upper Mississippi River and the Lower Mississippi River. The Upper Mississippi River stretches from Cairo, IL to Minneapolis, MN while the Lower Mississippi River is considered the portion of river between New Orleans, LA and Cairo, IL. The division of the river into these particular sections is due to the differences in river attributes along each section. The Upper Mississippi River uses a series of locks to allow transportation on the northern part of the Mississippi River, transportation that would not occur in the absence of the locks. South of Cairo, IL. no locks are present due to the depth of this portion of the river. Because the locks slow traffic along the river as barges must pass through one at a time, the Upper Mississippi is usually considered a separate waterway. Not surprisingly, the amount of traffic on the river system increases as one moves down river as shown in Table 3-1. Note that this table has the Mississippi River divided into three not two sections. In Table 3-1 the Upper Mississippi is the section of the river between Minneapolis, MN and the mouth of the Missouri River. The Middle Mississippi is the section of river between the mouth of the Missouri River and the mouth of the Ohio River. Finally, the Lower Mississippi is below the mouth of the Ohio River. Notice that traffic on the Lower Mississippi is more than double that on the Upper Mississippi, with traffic in the Middle Mississippi being approximately 50% larger than that on the Upper Mississippi.

TABLE 3-1: Total Waterborne Commerce on the Mississippi River by Section, 1993-2002

Upper Mississippi	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Farm Products	39.1	37.9	46.8	45.7	41.1	40.8	47.8	43.9	41.0	46.8
Metals	3.3	6.1	5.0	3.9	4.7	5.5	4.9	6.0	4.2	5.2
Coal	8.4	10.3	9.0	8.6	7.5	8.8	8.6	7.9	7.6	7.4
Crude Petroleum	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Nonmetallic Minerals	7.3	8.8	8.6	8.0	9.5	8.5	9.7	10.2	10.4	10.0
Forest Products	0.1	0.2	0.3	0.3	0.2	0.3	0.3	0.4	0.3	0.4
Industrial Chem	3.6	4.3	4.0	3.8	4.1	4.2	3.9	3.9	3.4	3.5
Agricultural Chem	3.8	4.5	3.7	3.3	3.0	3.4	3.2	3.4	3.5	3.5
Petroleum Products	6.4	7.4	6.8	6.7	7.7	8.0	7.3	7.5	8.2	7.2
Other	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0
Total	72.2	79.4	84.4	80.4	77.8	79.6	85.7	83.3	78.8	84.1
Middle Mississippi	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Farm Products	48.8	46.6	56.0	54.6	51.9	51.6	59.8	55.3	52.5	57.4
Metals	4.3	7.5	6.6	5.2	6.1	7.2	6.2	7.9	5.6	6.3
Coal	19.5	22.1	22.7	23.1	22.2	23.1	22.9	23.4	24.2	23.8
Crude Petroleum	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.0
Nonmetallic Minerals	12.2	15.8	17.4	14.8	16.7	16.9	20.0	18.5	19.2	17.4
Forest Products	0.2	0.3	0.3	0.4	0.3	0.4	0.5	0.7	0.4	0.4
Industrial Chem	3.9	4.6	4.4	4.3	4.5	4.7	4.5	4.4	3.9	4.0
Agricultural Chem	4.6	5.2	4.4	4.0	3.8	4.1	3.7	3.9	4.3	4.2
Petroleum Products	5.6	6.7	6.2	6.6	6.9	7.7	7.0	7.4	8.8	7.9
Other	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0
Total	99.1	108.9	118.3	113.0	112.5	115.8	124.7	121.6	119.1	121.5

Lower Mississippi	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Farm Products	73.3	68.0	79.1	75.6	71.8	69.7	79.1	77.3	78.1	80.6
Metals	14.7	20.9	20.8	19.7	20.6	22.9	23.3	26.9	21.0	24.1
Coal	34.2	35.4	32.8	30.7	29.3	28.4	23.7	23.8	25.0	22.5
Crude Petroleum	1.1	1.9	2.2	2.0	2.2	2.2	2.4	2.1	1.6	1.3
Nonmetallic Minerals	23.3	30.0	31.1	29.3	31.2	31.6	36.7	33.4	31.8	29.7
Forest Products	0.8	0.9	0.8	1.3	1.5	1.3	1.1	1.3	0.7	0.7
Industrial Chem	10.4	11.1	11.1	11.0	11.2	10.9	10.7	10.7	10.0	10.0
Agricultural Chem	8.7	9.5	8.9	8.0	7.9	8.5	8.2	8.4	9.5	8.6
Petroleum Products	17.1	18.7	17.9	18.1	18.1	19.8	19.3	20.2	22.8	20.9
Other	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.2	0.1
Total	183.8	196.8	205.1	195.9	193.9	195.9	204.9	204.3	200.6	198.3

Source: *Waterborne Commerce of the United States, Calendar Year 2002, Part 2 – Waterways and Harbors Gulf Coast, Mississippi River System and Antilles, U.S. Army Corps of Engineers (2003)*

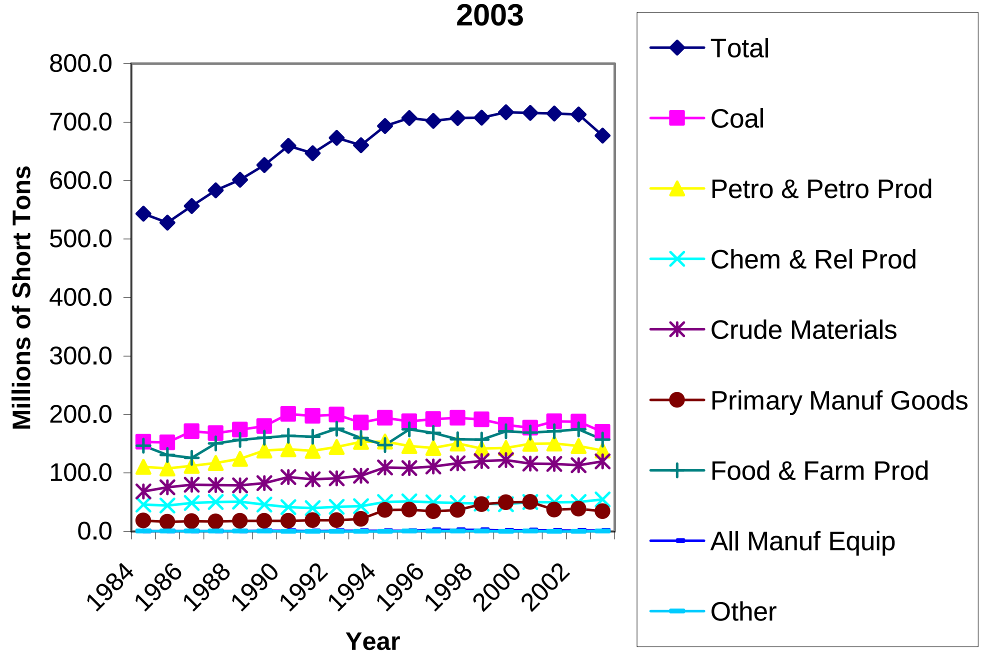
Stepping back even further, the Mississippi River Main Stem is part of a yet larger grouping, the Mississippi River System shown below in Figure 3-1. This designation of 'system', in its widest definition, includes also the Ohio River Basin, discussed below. As such, the Mississippi River System is inclusive of the Ohio River and its seven arteries.

Figure 3-1: The Mississippi River System

3.2 ATTRIBUTES

Figure 3-2 and Table 3-2 show the total waterborne commerce by commodity for the Mississippi River system. Coal is the Mississippi System's dominant quantity carried, totaling 25.2% of all commerce transported in 2003. However, coal is closely matched in relative percentages with two other commodity categories: Food and Farm Products (23.2%) as well as Petroleum and Petroleum Products (20.5%).

FIGURE 3-2: Total Waterborne Commerce by Commodity for the Mississippi River System, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-2*

TABLE 3-2: Total Waterborne Commerce by Commodity, 1984-2003 (millions of short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	543.5	527.8	556.4	583.4	601.6	626.4	659.1	646.6	673.1	660.4
Coal	153	152	171.1	167.9	173.8	180.3	200.8	197.5	199.7	186.1
Petro & Petro Prod	110.5	107.6	112.1	116.9	124.4	138.2	140.9	137.9	144.6	153
Chem & Rel Prod	45.7	44.4	48.6	50.6	50.8	45.8	41.8	40	42	43.5
Crude Materials	68.2	75.6	80	79.5	78.6	82.6	92.8	89	91.1	95.4
Primary Manuf Goods	18.6	16.5	17.5	17.1	18.3	18.1	18.3	19.4	18.9	21.6
Food & Farm Prod	146.5	130.6	125.8	150.4	156.4	160.1	163.4	161.9	175.7	159.6
All Manuf Equip	0.6	0.7	0.8	0.6	0.8	1.1	1	0.8	0.9	1.1
Other	0.4	0.4	0.3	0.4	0.4	0.4	0.1	0.1	0.2	0.2
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	693.3	707.2	701.8	707.1	707.4	716.9	715.5	714.8	712.8	676.8
Coal	194.2	188.1	192.3	194.2	191.5	182.4	177.2	188.4	187.9	170.3
Petro & Petro Prod	153.6	146.2	143.0	150.3	141.6	143.0	150.0	150.6	146.3	138.7
Chem & Rel Prod	50.3	51.4	49.9	48.9	47.4	46.6	50.3	49.9	50.4	54.5
Crude Materials	109.7	108.3	111.0	116.6	120.5	121.9	115.8	115.7	113.0	120.0
Primary Manuf Goods	36.5	37.3	34.6	36.7	46.5	49.8	50.4	37.0	39.0	34.2
Food & Farm Prod	147.7	174.5	168.3	157.6	157.0	171.2	169.0	171.1	174.4	157.2
All Manuf Equip	1.1	1.2	2.5	2.5	2.6	1.8	2.1	1.8	1.5	1.5
Other	0.2	0.3	0.3	0.3	0.3	0.2	0.7	0.1	0.2	0.4

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-2*

Examining the Mississippi River itself, Table 3-3 and Figures 3-3 to 3-5 show the principle commodities shipped. Food and Farm Products are the dominant commodity carried (32.7% of total), reflecting the westerly geographical positioning of the Mississippi River itself relative to that of the system as a whole. Another inescapable trait in the river's positioning is the direct connection to the Gulf of Mexico. Here the strong flow of oil from offshore derricks as well as that imported from other countries pushes petroleum and its related products to be the Main Stem's second largest commodity, with 26.6% of the total shipments.

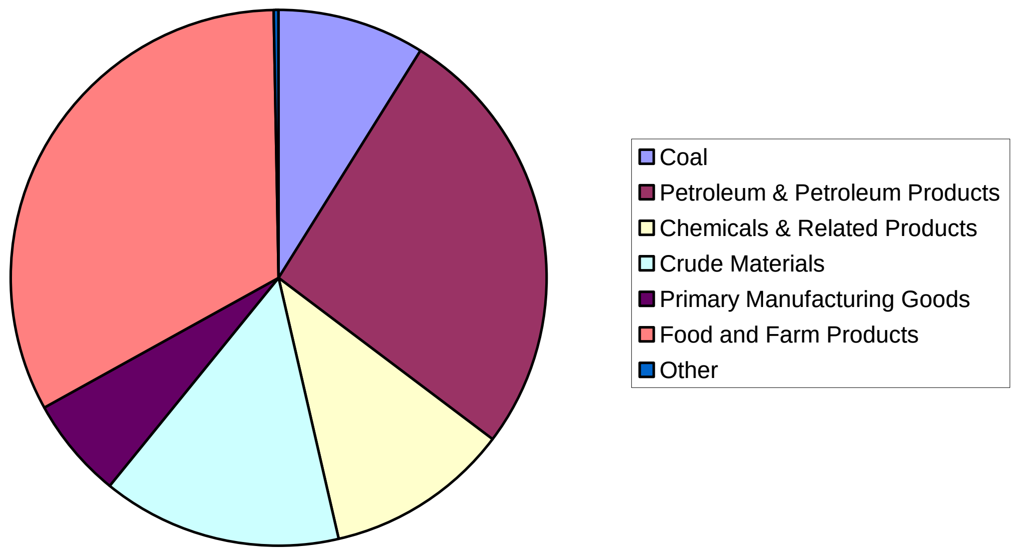
Foreign commerce upon the Main Stem of the Mississippi is largely reflective of that on the system as a whole, with two dominating commodities, Food and Farm Products as well as petroleum and its related products. Unlike system-wide domestic commerce, however, Main Stem domestic commerce is relatively more balanced between several commodities. Whereby coal captured 35% of system domestic shipments, less than 15% of Main Stem shipments are coal. Also noteworthy is that both chemicals and agricultural products each enlarged their relative percentages when moving from a Mississippi River System perspective to that of a Main Stem viewpoint.

TABLE 3-4: Principle Commodities in Waterborne Commerce for the Mississippi River Main Stem, 2002-2003 (millions of short tons)

	2002	2003	% Change
Total Commerce	501.70	478.00	-4.7
Coal	46.3	42.2	-8.9
Petroleum & Petroleum Products	132.60	127.00	-4.2
Chemicals & Related Products	48.5	52.7	8.5
Crude Materials	64.9	68.3	5.2
Primary Manufacturing Goods	34.1	29.5	-13.4
Food and Farm Products	173.5	156.5	-9.8
Other	1.7	1.8	5.3
Foreign Commerce	185.50	169.70	-8.5
Coal	2.2	3.1	40.9
Petroleum & Petroleum Products	55.5	48.2	-13.2
Chemicals & Related Products	13	14.9	14.1
Crude Materials	13.5	15.4	14.5
Primary Manufacturing Goods	13.1	9.5	-27.2
Food and Farm Products	87.4	77.8	-11
Other	0.8	0.9	7.6
Domestic Commerce	316.20	308.20	-2.5
Coal	44.1	39.1	-11.4
Petroleum & Petroleum Products	77.2	78.8	2.2
Chemicals & Related Products	35.5	37.8	6.4
Crude Materials	51.4	52.8	2.8
Primary Manufacturing Goods	21	20	-4.8
Food and Farm Products	86.1	78.8	-8.6
Other	0.9	0.9	3.2

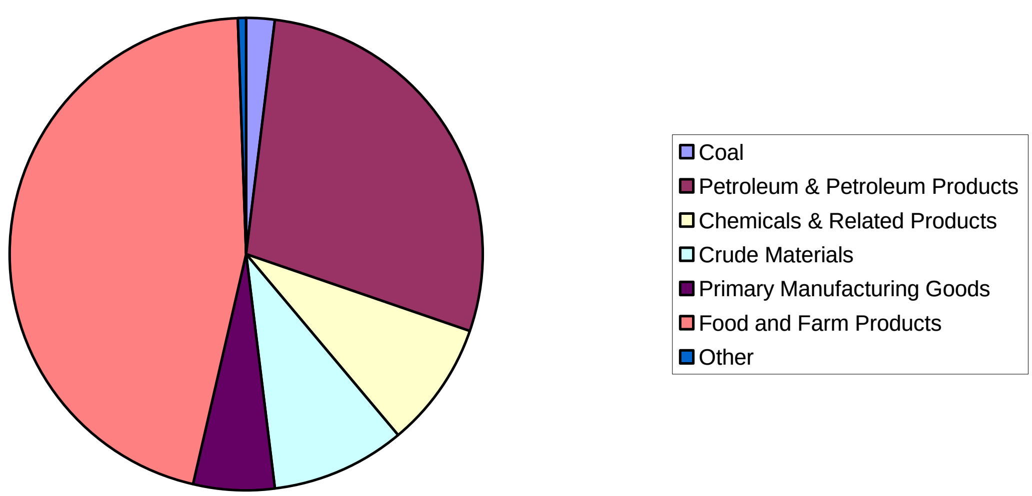
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-7*

FIGURE 3-3: Principle Commodities in Waterborne Commerce for the Mississippi River Main Stem, 2003 (Total)



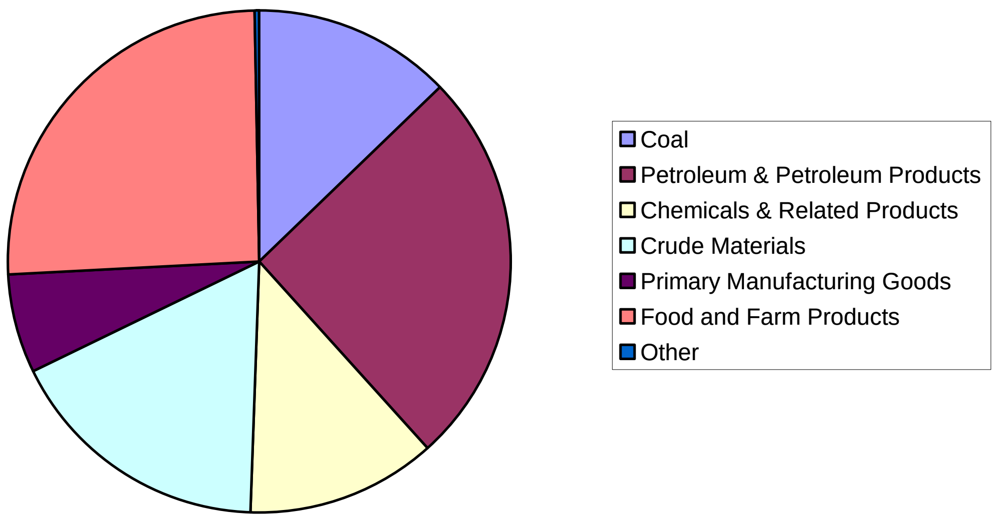
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-7*

FIGURE 3-4: Principle Commodities in Waterborne Commerce for the Mississippi River Main Stem, 2003 (Foreign)



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-7*

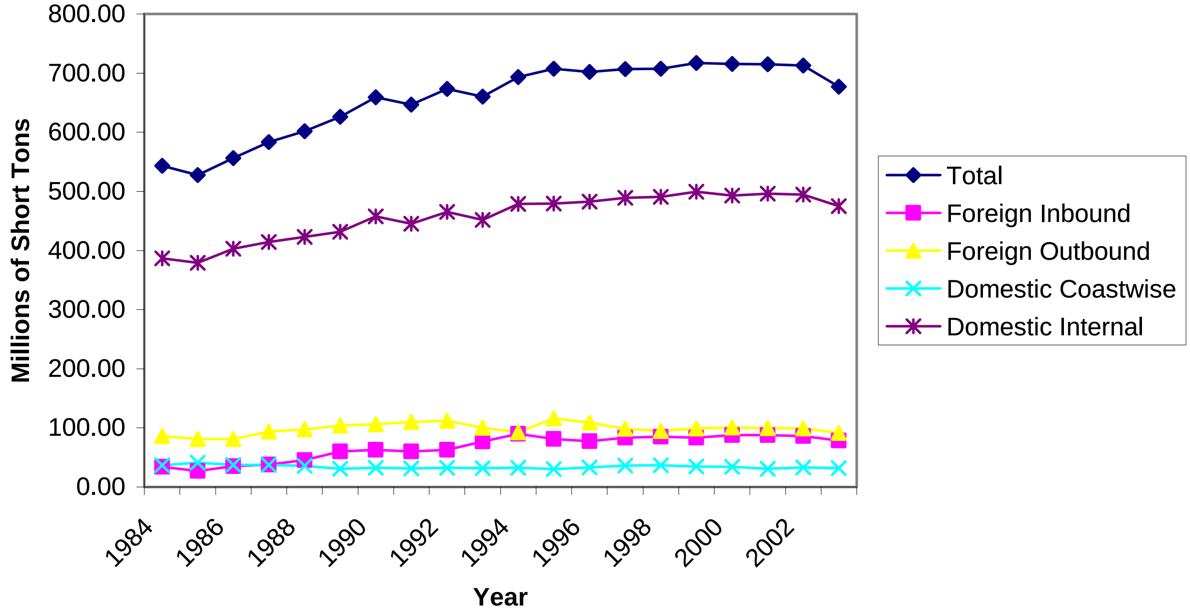
FIGURE 3-5: Principle Commodities in Waterborne Commerce for the Mississippi River Main Stem, 2003 (Domestic)



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-7*

Changing focus from a static positioning to that of a timeline, the Mississippi System has seen increasing usage as a waterway for freight traffic, as one may see from figure 3-6 and table 3-4. Specifically, since 1984, total commerce has increased from approximately 544 to 677 million tons (through 2003). This appears to be essentially a result of increasing domestic (internal) traffic. Further, traffic designated as domestic internal (as opposed to domestic *coastwise* shipments) accounted for nearly 70% of all traffic system-wide for 2001.

FIGURE 3-6: Types of Traffic on the Mississippi River System, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-1*

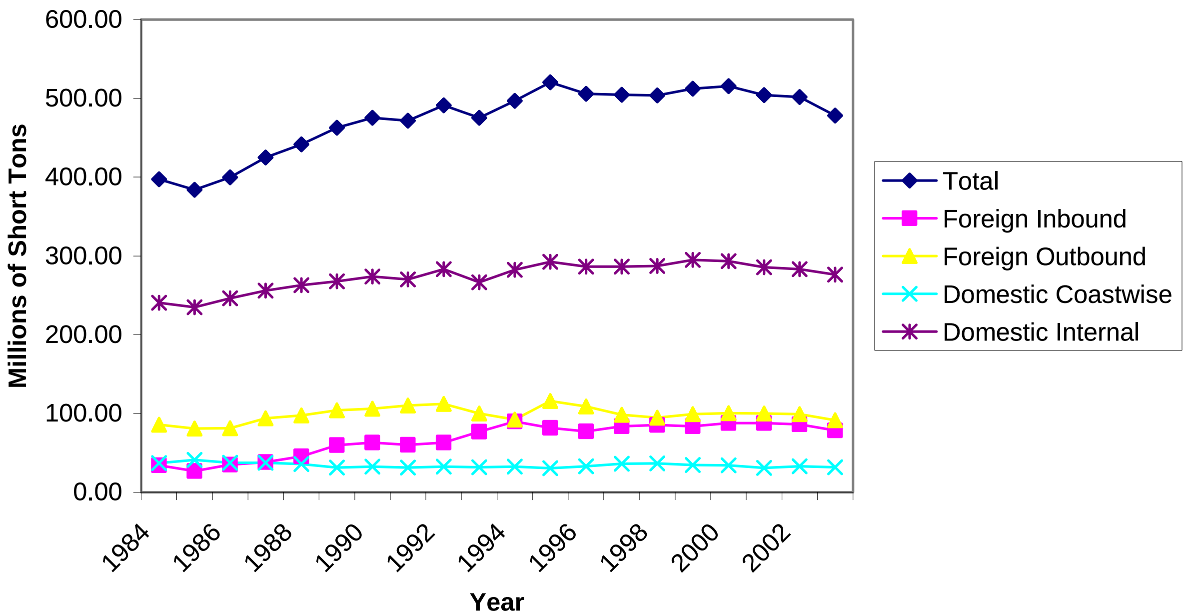
TABLE 3-4: Types of Traffic on the Mississippi River System, 1984-2003 (million short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	543.50	527.80	556.40	583.40	601.60	626.40	659.10	646.60	673.10	660.40
Foreign Inbound	34.1	27	35.1	38.1	45.3	59.9	63.1	60.1	63	76.9
Foreign Outbound	85.9	81	81.1	93.7	97.5	104	106	109.9	112.3	100
Domestic Coastwise	36.7	40.9	37.4	37.4	35.8	31.1	32.6	31.3	32.3	31.8
Domestic Internal	386.6	378.9	402.8	414.2	423	431.5	457.5	445.1	465.4	451.7
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	693.30	707.20	701.80	707.10	707.40	716.90	715.50	714.80	712.80	676.80
Foreign Inbound	89.8	81.5	77.3	83.5	85.2	83.5	87.7	87.8	86.3	78.4
Foreign Outbound	92.4	115.8	108.7	98.5	94.7	99.2	100.5	99.8	99.2	91.3
Domestic Coastwise	32.4	30.6	33	36.3	36.7	34.6	34.1	30.9	33	31.8
Domestic Internal	478.7	479.4	482.8	488.9	490.7	499.6	493.1	496.3	494.3	475.2

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-1*

Figure 3-7 and Table 3-5 show a similar increase in commerce along the Mississippi River's Main Stem over this period of time. Again, domestic internal traffic was the dominant type of traffic. Foreign traffic, measured in millions of (short) tons for both inbound and outbound shipments, was identical for the entire Mississippi System as well as the Main Stem portion. In 2003, foreign inbound amounted to 78.4 million tons while outbound registered 91.3 million tons.

FIGURE 3-7: Types of Traffic on the Mississippi River Main Stem, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-5*

TABLE 3-5: Types of Traffic on the Mississippi River Main Stem, 1984-2003 (million short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	397.30	384.00	399.90	425.00	441.50	462.70	475.30	471.70	491.00	475.10
Foreign Inbound	34.1	27	35.1	38.1	45.3	59.9	63.1	60.1	63	76.9
Foreign Outbound	85.9	81	81.1	93.7	97.5	104	106	109.9	112.3	100
Domestic Coastwise	36.9	40.9	37.4	37.4	35.8	31.1	32.6	31.3	32.4	31.8
Domestic Internal	240.4	235	246.3	255.8	262.9	267.8	273.6	270.3	283.3	266.5
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	496.80	520.30	505.60	504.70	503.90	512.30	515.60	504.20	501.70	478.00
Foreign Inbound	89.8	81.5	77.3	83.5	85.2	83.5	87.7	87.8	86.3	78.4
Foreign Outbound	92.4	115.8	108.7	98.5	94.7	99.2	100.5	99.8	99.2	91.3
Domestic Coastwise	32.4	30.6	33	36.3	36.7	34.6	34.1	30.9	33	31.8
Domestic Internal	282.2	292.4	286.5	286.5	287.3	295	293.3	285.6	283.3	276.4

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table x-x*

THE OHIO RIVER BASIN

4.1 INTRODUCTION

Encompassing 2,800 miles of navigable waterway, the Ohio River Basin is a significant system for inland barge commerce. Dominated by its namesake, the Ohio River, the Basin was responsible for transporting a total of 275 million tons of commodities in 1999.

In addition to the Ohio River itself, the system itself incorporates seven other rivers (Tennessee, Cumberland, Monongahela, Allegheny, Green, Kanawha, and Big Sandy Rivers) which run through or adjacent to nine states, namely: Alabama, Illinois, Indiana, Kentucky, Mississippi, Ohio, Pennsylvania, Tennessee and West Virginia. Furthermore, barges that operate within the Ohio River Basin can be found originating from or terminating at 12 other states: Arkansas, Florida, Georgia, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, Oklahoma, Texas and Wisconsin.

Even after noting the breadth of the statewide area covered, the Ohio River itself remains the central artery within the Basin system, both in a static and dynamic sense. Geographically, the Ohio forms as the backbone for the system, stretching westward from Pittsburgh and flowing towards Cairo, Illinois, near its convergence with the Mississippi River. Additionally, the Ohio River also offers 981 miles of navigable waterway, the largest of the eight rivers that incorporate the Ohio River Basin (ORB) system. Dynamically, the Ohio acts as a funnel for the commerce traveling within the area. This is due both to the Ohio's geographic proximity (all rivers within the basin flow into the Ohio River) as well as its endpoint connection at the Mississippi River, itself a major artery for inland commerce. These two factors establish its relative dominance within the Basin system.

The Ohio River Basin waterway system offers many attractive attributes. The most attractive would most likely be that of its direct connection to the Mississippi River. It also contains a main artery, the Ohio River, which flows westward from a junction of two other waterways (Allegheny, Monongahela), connecting five other navigable passages. Additionally, it is endowed with an abundance of coal and effective transportation underpinnings, namely the waterways themselves. These traits, when incorporated with an arrangement of 60 locks and dams, facilitate the movement of large-scale barge traffic. Although the foremost commodity carried by volume is coal, the waterway provides a mode of travel for other multi-use products such as petroleum, grains, and chemicals. Overall, given the fundamental needs to society that these commodities satisfy, one can be assured that they will be demanded, in voluminous quantity, for the foreseeable future.

4.2 ATTRIBUTES

Of the 261.3 million tons noted transported along the Ohio River Basin in 2003, the dominant commodity carried was coal, accounting for 53.9% of total waterborne commerce as shown below in Table 4-1 and Figures 4-1 and 4-2. Directionally, 48 million tons ebbed out of the ORB while 46 million tons flowed into the system from outside. Most significantly, approximately 180 million tons traversed and remained within the Basin itself. To accomplish this, the ORB is endowed with an infrastructure of approximately 1000 facilities, docks and terminals. Many of these serve large metropolitan areas with accompanying ports. Listed in order of total waterborne commerce, the top five major port interchanges (1999) were Pittsburgh (53 million tons), Huntington, W. Virginia (22.3), Cincinnati (14.3), followed by Louisville (8.8) and Nashville (4.7). To allow barge traffic to traverse this vast waterway which is forced to overcome elevation changes, the system is composed of 60 lock and dam facilities. The US

Army Corps of Engineers (USACE) maintains these facilities and is responsible for their care. Of these 60 locales, 20 reside on the Ohio, nine each upon the Monongahela and Tennessee, the Allegheny follows with (8), the Cumberland (4), and the Kanawha and Green Rivers each with three. The remaining five facilities are located on the Kentucky (4) and Clinch Rivers (1), which are navigable and still in use but do not have any cargo tonnage.

As mentioned earlier, coal is the primary commodity hauled, encapsulating over half of all barge traffic. Utility companies are the principal recipients of these coal shipments, with 49 power plants located within the Basin and 12 others residing within neighboring states, also connected via waterways. Specifically, in 1999 power plants utilized 120 of the 151 million tons shipped within the Basin's waters, which encapsulated 79% of all coal shipped. The reason for this is twofold. First, coal is offered in abundance from within the region in high, low and medium sulfur contents. Second, the large river system encourages power plants to agglomerate nearby since they can utilize the waterway for two purposes: in-plant water needs as well as an efficient mode for receiving coal, a primary input for utilities.

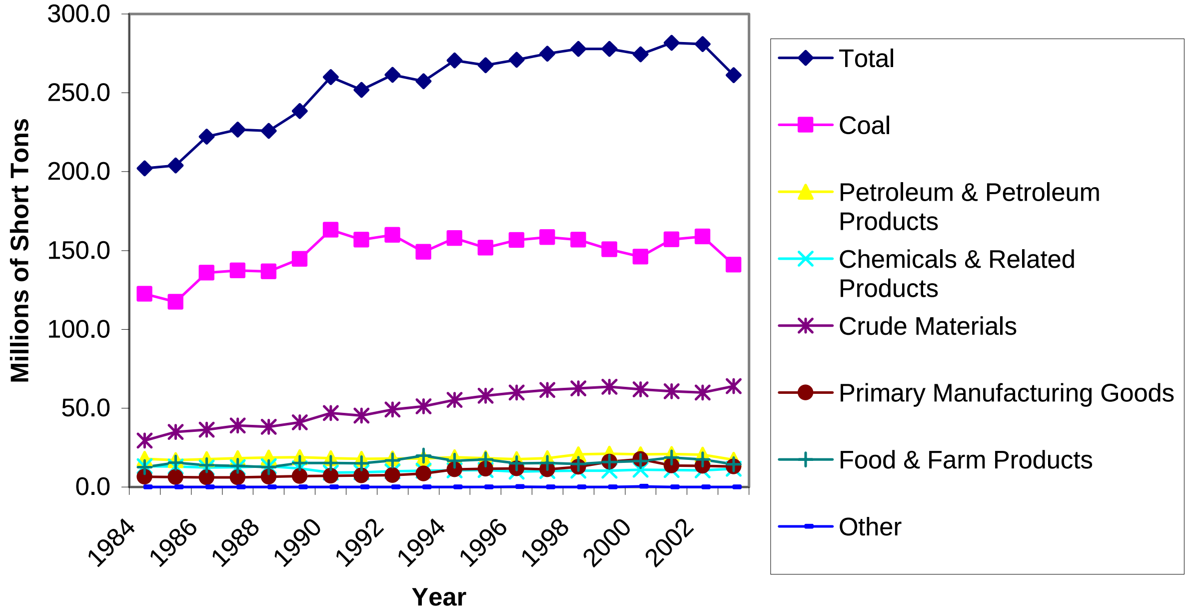
Regarding aggregate quantities, W. Virginia was the leading shipper of coal (40 million tons) with Kentucky and Illinois following (31 and 21 million tons, respectively). Leading receivers for coal shipments were Ohio (30.5), Indiana (17) and W. Virginia (16). Kentucky held the largest number of coal-fired power plants (12) with Ohio being in second, with 11.

TABLE 4-1: Total Waterborne Commerce by Commodity for the Ohio River System, 1984-2003 (millions of short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	202.2	203.9	222.2	226.7	225.9	238.4	260.0	251.9	261.4	257.3
Coal	122.5	117.3	135.9	137.3	136.7	144.6	163	156.8	159.8	149
Petroleum & Petroleum Products	17.9	17.1	17.6	18.2	18.6	18.8	18.3	17.8	18	18.1
Chemicals & Related Products	13.2	12.9	12.4	12.6	13.3	11.7	9.1	9.4	10	10.4
Crude Materials	29.4	34.9	36.4	39	38.1	41	47	45.3	49.1	51.1
Primary Manufacturing Goods	6.6	6.2	6.1	6.1	6.5	7	7.2	7.4	7.5	8.6
Food & Farm Products	12.5	15.4	13.8	13.5	12.5	15.2	15.3	15	16.9	20
Other	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	270.5	267.6	270.9	274.9	277.9	277.9	274.4	281.8	280.9	261.3
Coal	157.9	151.7	156.5	158.4	156.9	150.8	146.1	157.1	158.8	140.9
Petroleum & Petroleum Products	18.9	18.2	17.7	18.3	20.7	21.1	20.8	20.9	20.5	17.2
Chemicals & Related Products	10.6	10.7	9.8	10.1	10.3	10.3	10.9	10.7	10.6	11.5
Crude Materials	55.3	57.9	60.0	61.5	62.6	63.6	62.0	60.7	59.9	64.0
Primary Manufacturing Goods	11.2	11.6	11.7	11.1	12.7	16.1	17.7	13.6	13.4	13.1
Food & Farm Products	16.6	17.4	15.0	15.3	14.7	15.8	16.4	18.6	17.5	14.4
Other	0.1	0.1	0.2	0.0	0.1	0.1	0.5	0.1	0.1	0.1

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-8*

FIGURE 4-1: Total Waterborne Commerce by Commodity for the Ohio River System, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-8*

Figure 4-1 and Table 4-1 show that crude materials are the second largest commodity carried along the Ohio Basin System accounting for 24.5% of total waterborne commerce followed by petroleum and petroleum related products accounting for 6.6%. The demand for barge-transported petroleum products is driven by the fact that many Basin cities are without a connection to the petroleum product pipelines. Additionally, some products such as asphalt and residual fuel oils cannot be moved via pipelines, simply due to their physical properties. To meet this demand, there are 250 tank farms, terminals or affiliated facilities for petroleum products.

THE GULF INTERCOASTAL WATERWAY

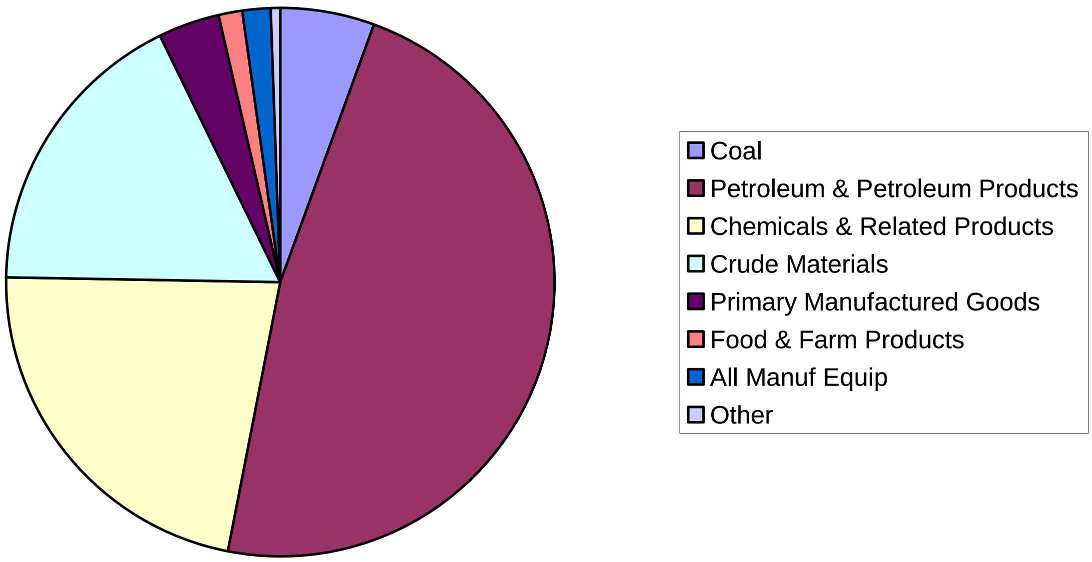
5.1 INTRODUCTION

Unlike the river systems discussed above, the Gulf Intercoastal Waterway (GIWW) is the largest component (1,109 miles) of a larger waterway system, labeled the Gulf Coast (comprising 1,992 miles). However, the Gulf Coast System is composed of various small rivers, navigable bayous and channels. It is more sprawling and haphazard than the easily defined and collected waterways such as the Mississippi or Ohio rivers. Instead, smaller samplings such as the Chocolate Bayou in Texas (13 miles) or Alabama's Black Warrior and Tombigbee Rivers make up compositional parts to the wider, Gulf System. Furthermore, the Gulf Intercoastal Waterway is itself bisected into two parts, an eastern portion as well the expected western section. The eastern portion stretches along the Gulf of Mexico from New Orleans to Key West while the western part encompasses New Orleans to Brownsville, Texas.

5.2 ATTRIBUTES

Given the GIWW's geographic positioning, petroleum is the dominant commodity, as depicted in Figure 5-1 and Table 5-1. As such, 47.6% of traffic was that of petroleum and its related products in 2003. The next largest commodities transported along the GIWW are chemicals (22.2%) and while crude materials (17.6%). All other commodities were 5.5% or less.

Figure 5-1: Principle Commodity Groups Transported on the Gulf Intercoastal Waterway, 2003



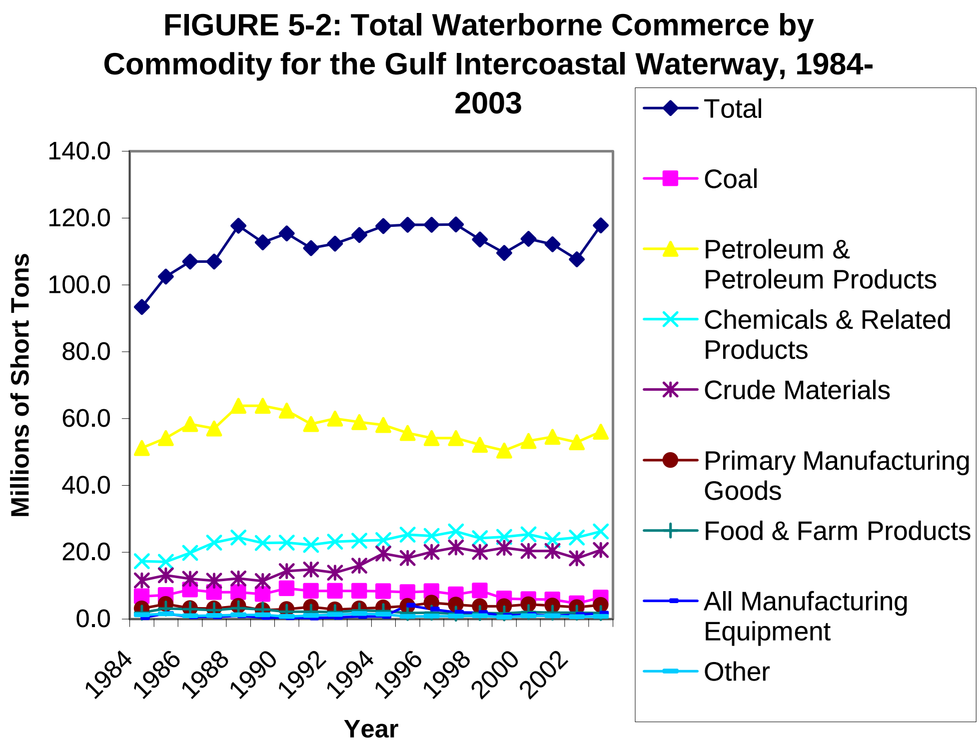
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-15*

TABLE 5-1: Principle Commodities in Waterborne Commerce for the Gulf Intercoastal Waterway, 2002-2003 (millions of short tons)

	2002	2003	% Change
Total Commerce	107.70	117.80	9.5
Coal	4.7	6.4	35.1
Petroleum & Petroleum Products	52.90	56.10	6.2
Chemicals & Related Products	24.4	26.2	7.3
Crude Materials	18.2	20.7	13.3
Primary Manufactured Goods	3.5	4.2	20.4
Food & Farm Products	1.9	1.8	-8.4
All Manuf Equip	1.3	1.7	37.2
Other	0.7	0.8	6

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-15*

Figure 5-2 and Table 5-2 show that over time, total shipments have displayed a slight upward trend. By commodity, there is little change in the composition of total waterborne commerce on the Gulf Intercoastal Waterway over the years 1983-2003.



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-14*

TABLE 5-2: Total Waterborne Commerce by Commodity for the Gulf Intercoastal Waterway, 1984-2003 (millions of short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	93.4	102.5	107.0	107.0	117.7	112.7	115.4	111.0	112.3	114.9
Coal	6.8	7.2	8.8	8	8	7.5	9.2	8.4	8.4	8.4
Petroleum & Petroleum Products	51.2	54.2	58.4	57	63.8	63.8	62.4	58.4	60	58.9
Chemicals & Related Products	17.3	17.1	19.8	22.9	24.4	22.8	22.9	22.2	23.2	23.4
Crude Materials	11.6	13.1	12.1	11.5	12.2	11.4	14.4	14.8	13.9	16
Primary Manufacturing Goods	3.2	4.5	3.3	3.2	3.9	2.7	3	3.6	2.9	3.2
Food & Farm Products	1.9	3.2	3	2.7	3.3	2.9	2.2	2.2	2.1	2.6
All Manufacturing Equipment	0.4	1.6	0.7	0.7	1	0.5	0.4	0.3	0.5	0.8
Other	1.2	1.5	1	1.1	1.2	1.2	0.8	1.1	1.3	1.6
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	117.6	118.0	118.0	118.1	113.6	109.6	113.8	112.2	107.7	117.8
Coal	8.3	8.0	8.3	7.4	8.5	6.1	5.9	5.8	4.7	6.4
Petroleum & Petroleum Products	58.1	55.7	54.2	54.2	52.2	50.4	53.3	54.5	52.9	56.1
Chemicals & Related Products	23.6	25.3	24.9	26.2	24.2	24.6	25.4	23.7	24.4	26.2
Crude Materials	19.6	18.3	20.1	21.4	20.1	21.3	20.4	20.4	18.2	20.7
Primary Manufacturing Goods	3.4	3.9	4.9	4.3	3.8	3.8	4.4	4.0	3.5	4.2
Food & Farm Products	2.4	1.8	1.9	1.6	1.8	1.7	2.1	1.9	1.9	1.8
All Manufacturing Equipment	0.8	4.1	3.0	2.0	1.9	1.1	1.3	1.0	1.3	1.7
Other	1.4	0.8	0.9	0.9	1.0	0.6	1.0	1.0	0.7	0.8

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-14*

Total commerce transported via the GIWW is essentially a function of domestic internal movements as shown in Figure 5-3 and in Table 5-3.

TABLE 1-4: Types of Traffic on the Gulf Intercoastal System, 1984-2003 (million short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992
Total	93.40	102.50	107.00	107.00	117.70	112.70	115.40	111.00	112.30
Foreign Inbound	-	0	0	0	0.4	0.3	-	-	-
Foreign Outbound	0	0	0.1	0	0.2	0.1	-	-	-
Domestic Coastwise	1	1.1	1.2	0.9	1.2	0.8	0.7	0.7	0.7
Domestic Internal	92.4	101.3	105.7	106.1	115.9	111.6	114.6	110.3	111.6
	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total	117.60	118.00	118.00	118.10	113.60	109.60	113.80	112.20	107.70
Foreign Inbound	-	-	-	-	-	-	-	-	-
Foreign Outbound	-	-	-	-	-	-	-	-	-
Domestic Coastwise	1.3	1.2	1.1	1.3	1.9	1.9	0.8	0.7	0.8
Domestic Internal	116.3	116.8	116.9	116.8	111.6	107.7	113	111.5	106.9

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-13*

TABLE 5-3: Types of Traffic on the Gulf Intercoastal System, 1984-2003 (million short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	93.40	102.50	107.00	107.00	117.70	112.70	115.40	111.00	112.30	114.90
Foreign Inbound	-	0	0	0	0.4	0.3	-	-	-	-
Foreign Outbound	0	0	0.1	0	0.2	0.1	-	-	-	-
Domestic Coastwise	1	1.1	1.2	0.9	1.2	0.8	0.7	0.7	0.7	0.9
Domestic Internal	92.4	101.3	105.7	106.1	115.9	111.6	114.6	110.3	111.6	114.1
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	117.60	118.00	118.00	118.10	113.60	109.60	113.80	112.20	107.70	117.80
Foreign Inbound	-	-	-	-	-	-	-	-	-	-
Foreign Outbound	-	-	-	-	-	-	-	-	-	-
Domestic Coastwise	1.3	1.2	1.1	1.3	1.9	1.9	0.8	0.7	0.8	0.7
Domestic Internal	116.3	116.8	116.9	116.8	111.6	107.7	113	111.5	106.9	117.1

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-13*

THE PACIFIC COAST: COLUMBIA, SNAKE & WILLAMETTE RIVERS

6.1 INTRODUCTION

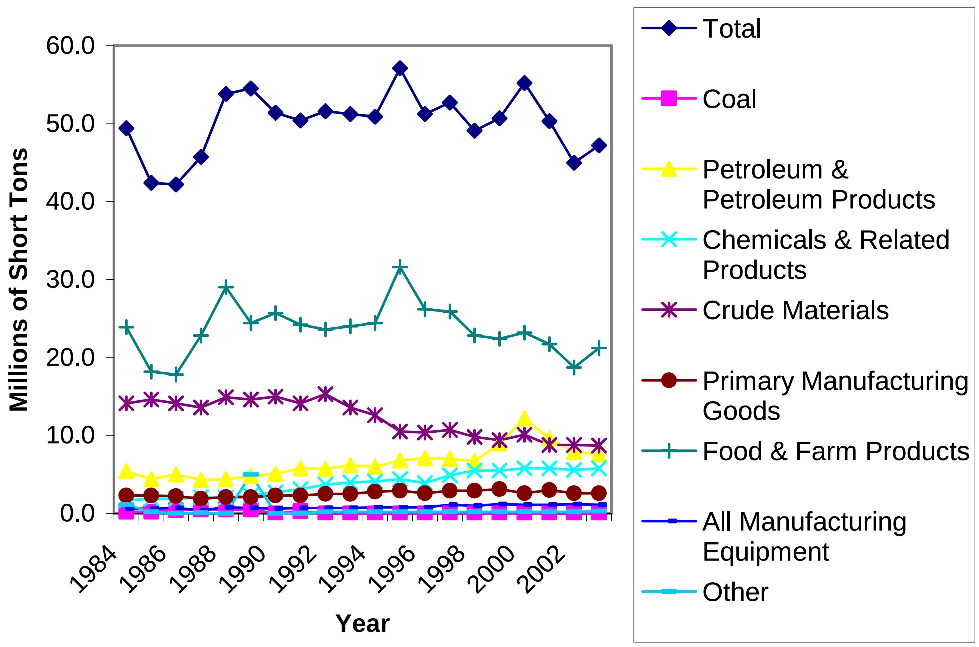
Slightly different than the interconnected and overlapping nature of the waterway systems examined thus far, the Columbia River System is independent of any other waterway connections, save the Pacific Ocean. Composed of three rivers (the Columbia, Snake, and Willamette) the entire system encompasses only 596 navigable miles, 141 miles of which is attributed to the Snake. Meanwhile, the Willamette River, which is navigable northward from Portland, Oregon to its meeting with the Columbia, encapsulates a total distance of 118 miles.

6.2 ATTRIBUTES

Figure 6-1 and Table 6-1 show the total waterborne commerce from 1984-2003 for the Columbia River, while Figure 6-2 and Table 6-2 illustrate this same measure for the Snake River. The Columbia River's principle commodity is agricultural products (Food and Farm Products), which was responsible for 44.9% of all river commerce in 2003. Crude materials were the second most transported commodity on the Columbia River (18.4%), while petroleum products were third (16.1%). For the Snake River, the top three commodities are the same as for the Columbia: Food and Farm Products (59.8%), Petroleum Products (34.2%) and Crude Materials (3.8%).

Over time, total traffic upon each river has been relatively stagnant. However, there have been large fluctuations in total traffic over short periods of time, with these fluctuations being caused by the fluctuations in Food and Farm Products being transported.

FIGURE 6-1: Total Waterborne Commerce by Commodity for the Columbia, 1984-2003



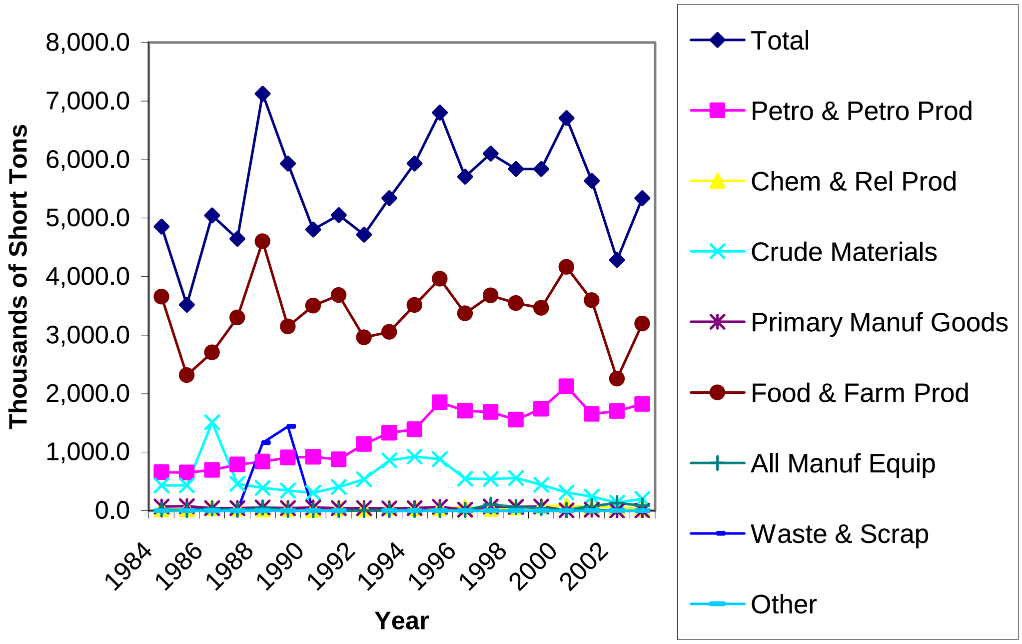
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-17*

TABLE 6-1: Total Waterborne Commerce by Commodity for Columbia, 1984-2003 (millions of short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	49.4	42.4	42.2	45.7	53.8	54.5	51.4	50.4	51.6	51.2
Coal	0.2	0.2	0.4	0.5	0.5	0.5	0	0.3	0	0
Petroleum & Petroleum Products	5.4	4.4	5	4.3	4.4	4.8	5.1	5.8	5.7	6.2
Chemicals & Related Products	1.7	1.9	1.9	2.1	2	2.3	2.7	3.1	3.7	4
Crude Materials	14.1	14.6	14.1	13.6	14.9	14.6	15	14.1	15.3	13.6
Primary Manufacturing Goods	2.3	2.3	2.2	1.9	2.1	2.1	2.3	2.3	2.5	2.5
Food & Farm Products	23.9	18.2	17.8	22.8	29	24.4	25.7	24.2	23.6	24
All Manufacturing Equipment	0.6	0.6	0.7	0.4	0.8	0.7	0.6	0.7	0.7	0.7
Other	1.1	0.2	0	0.1	0	5	0	0	0.2	0.2
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	50.9	57.1	51.2	52.7	49.1	50.7	55.2	50.3	45.0	47.2
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum & Petroleum Products	6.0	6.8	7.1	7.0	6.7	9.0	12.2	9.6	7.9	7.6
Chemicals & Related Products	4.1	4.4	3.9	4.9	5.5	5.5	5.8	5.8	5.6	5.8
Crude Materials	12.6	10.5	10.4	10.7	9.8	9.4	10.1	8.8	8.8	8.7
Primary Manufacturing Goods	2.8	2.9	2.6	2.9	2.9	3.1	2.6	3.0	2.6	2.6
Food & Farm Products	24.4	31.6	26.2	25.9	22.8	22.4	23.2	21.7	18.7	21.2
All Manufacturing Equipment	0.8	0.8	0.8	1.1	1.0	1.2	1.1	1.1	1.2	1.1
Other	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-17*

FIGURE 6-2: Total Waterborne Commerce by Commodity for the Snake, 1984-2003



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-19*

TABLE 6-2: Total Waterborne Commerce by Commodity for Snake, 1984-2003 (millions of short tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Total	4,852.0	3,518.8	5,042.6	4,644.9	7125.1	5930.3	4804.0	5053.2	4719.3	5339.1
Petro & Petro Prod	654	652.7	694.8	789.5	839.1	908.4	920	875.1	1,140.40	1,328.90
Chem & Rel Prod	26.3	27.2	45.2	36.2	22.9	33.1	14.8	41.3	35.4	50.9
Crude Materials	429.8	434.5	1,512.80	461.3	390.3	347.2	304.8	404.1	533.6	858.6
Primary Manuf Goods	71.7	74.4	45.9	45.6	52.2	45.3	53.8	45	43.2	40
Food & Farm Prod	3,653.50	2,316.80	2,704.40	3,301.30	4,601.10	3,148.80	3,503.20	3,682.40	2,961.40	3,055.80
All Manuf Equip	16.7	13.2	38.5	10	57.2	9.9	7.3	5.3	5.3	4.9
Waste & Scrap	-	-	0.9	1	1,162.20	1,437.50	-	-		-
Other	-	-	-	-	-	-	-	-		-
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	5929.1	6803.9	5707.4	6102.5	5840.0	5836.5	6707.1	5638.7	4283.8	5339.1
Petro & Petro Prod	1391.3	1847.6	1708.8	1683.2	1556.0	1739.0	2120.5	1652.3	1704.5	1823.9
Chem & Rel Prod	43.4	41.3	52.0	30.5	53.2	74.3	88.4	59.2	59.9	34.7
Crude Materials	925.9	878.9	548.5	540.2	556.2	444.7	312.5	241.4	136.0	201.6
Primary Manuf Goods	46.0	64.5	18.0	69.8	66.6	71.5	7.8	15.6	2.2	-
Food & Farm Prod	3510.7	3963.6	3369.1	3677.6	3544.6	3461.9	4162.7	3594.8	2251.8	3193.1
All Manuf Equip	11.8	8.0	10.8	101.3	63.5	45.1	15.2	75.3	129.3	85.8
Waste & Scrap	-	-	0.2	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-

Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-19*

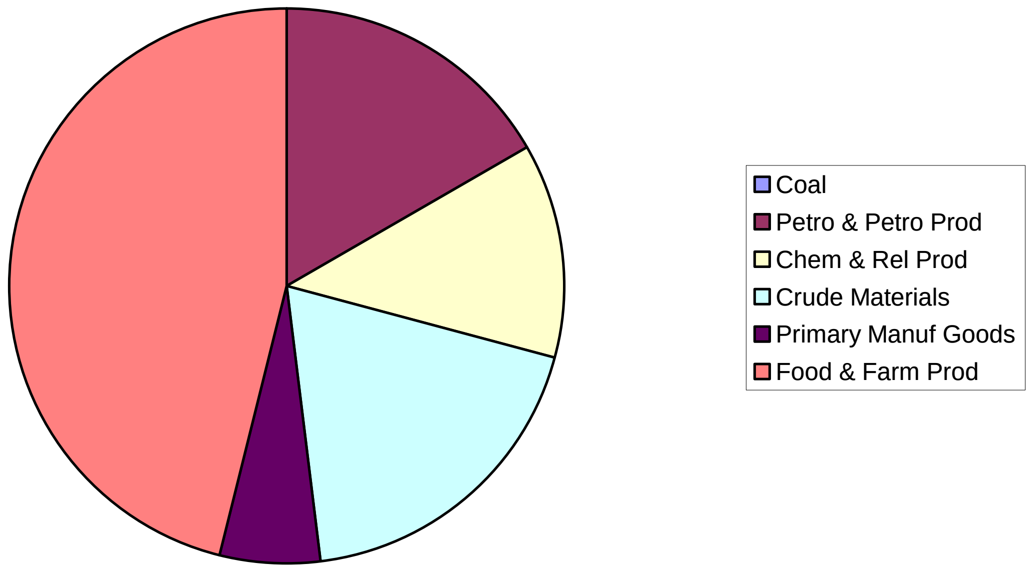
Of this traffic, foreign commerce made up 66.1% of the total tons shipped in 2003 on the Columbia River as shown in Table 6-3 and in Figures 6-3 through 6-5. Furthermore, the foreign commerce commodity distribution tends to mimic that of the commodity distribution of the Columbia as a whole, with agriculture products the leading quantity. However, domestic commerce differs significantly from that of foreign commerce. Here, petroleum and petroleum products account for 35.6% of domestic traffic.

TABLE 6-3: Principle Commodities in Waterborne Commerce for the Columbia, 2002-2003 (millions of short tons)

	2002	2003	% Change
Total Commerce	45.00	47.20	4.7
Coal	0	0	-99.7
Petro & Petro Prod	7.90	7.60	-4.4
Chem & Rel Prod	5.6	5.8	3.8
Crude Materials	8.8	8.7	-0.9
Primary Manuf Goods	2.6	2.6	0.5
Food & Farm Prod	18.7	21.2	12.9
All Manuf Equip	1.2	1.1	-7.8
Other	0.2	0.3	11.9
Foreign Commerce	29.50	31.20	5.7
Coal	0	0	-99.7
Petro & Petro Prod	1.8	1.8	1.3
Chem & Rel Prod	5.2	5.6	7.1
Crude Materials	3.7	4	9
Primary Manuf Goods	2.6	2.6	0.4
Food & Farm Prod	15.3	16.2	6.1
All Manuf Equip	1	1	2.3
Other	0.1	0.1	9.2
Domestic Commerce	15.50	16.00	2.9
Coal	0	0	-
Petro & Petro Prod	6.1	5.7	-6.1
Chem & Rel Prod	0.3	0.2	-47.7
Crude Materials	5.1	4.7	-8.1
Primary Manuf Goods	0.1	0.1	4.7
Food & Farm Prod	3.5	5	42.7
All Manuf Equip	0.2	0.1	-50.8
Other	0.2	0.2	9.1

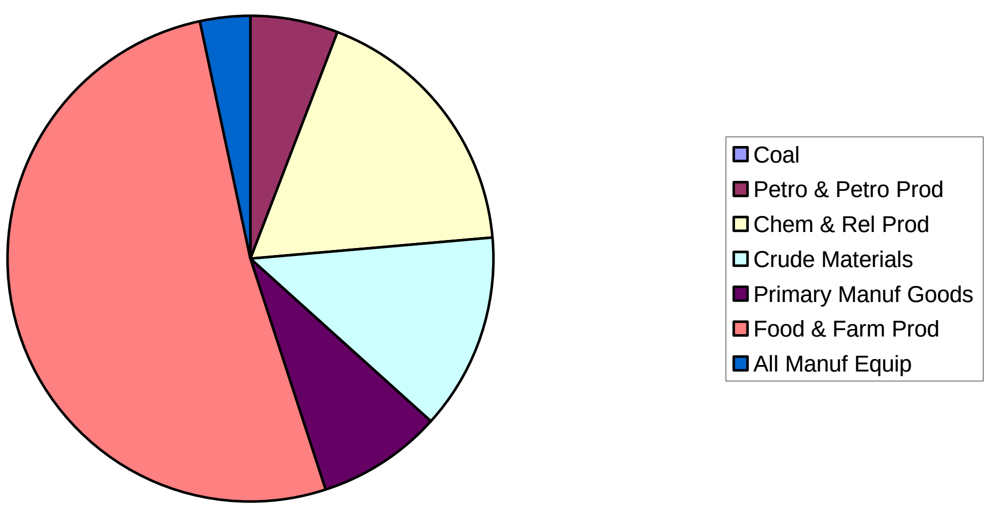
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-18*

FIGURE 6-3: Principle Commodities in Waterborne Commerce for the Columbia River, 2003 (Total)



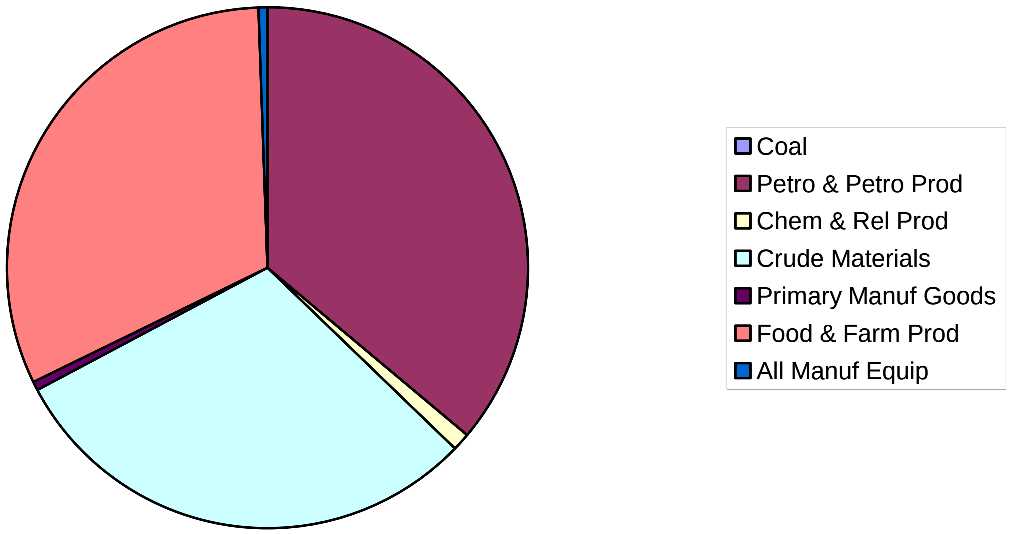
Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Table 3-18*

FIGURE 6-4: Principle Commodities in Waterborne Commerce for the Columbia River, 2003 (Foreign)



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-18*

FIGURE 6-5: Principle Commodities in Waterborne Commerce for the Columbia River, 2003 (Domestic)



Source: *Waterborne Commerce of the United States, Calendar Year 2003, Part 5 - National Summaries, U.S. Army Corps of Engineers (2004), Figure 3-18*

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The NETS research program is developing a series of practical tools and techniques that can be used by Corps navigation planners across the country to develop consistent, accurate, useful and comparable information regarding the likely impact of proposed changes to navigation infrastructure or systems.

The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting international and domestic traffic flows and how they may be affected by project improvements.
- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

As these models and other tools are finalized they will be available on the NETS web site:

http://www.corpsnets.us/toolbox.cfm

The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

http://www.corpsnets.us/bookshelf.cfm

NETS

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Information Transfer Program

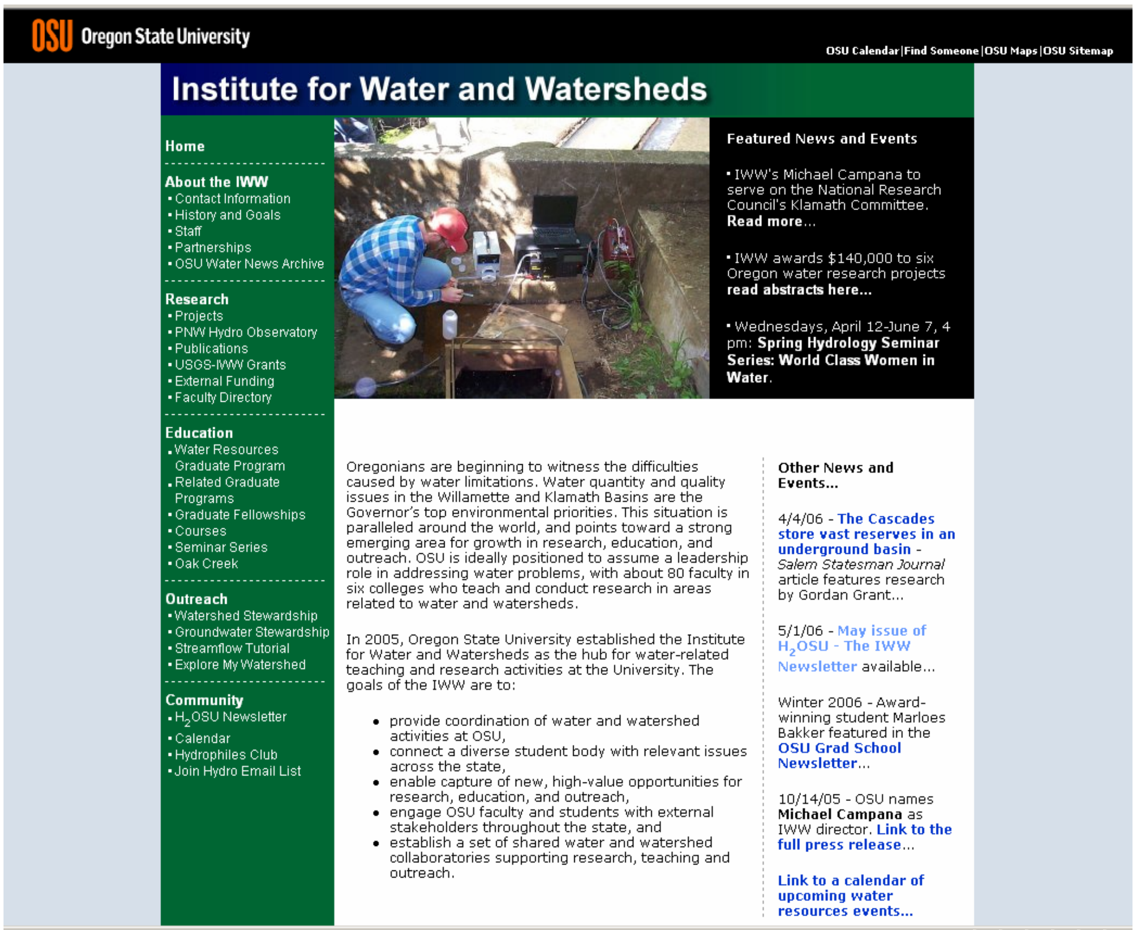
Technology Transfer

Basic Information

Title:	Technology Transfer
Project Number:	2005OR68B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Oregon
Research Category:	Climate and Hydrologic Processes
Focus Category:	Education, Law, Institutions, and Policy, Management and Planning
Descriptors:	
Principal Investigators:	Todd Jarvis

Publication

For 2005, the Institute for Water and Watersheds (IWW) participated and sponsored many events. IWW developed a new website and a monthly newsletter which can be viewed at **http://water.oregonstate.edu**.



IWW sponsored a fall seminar series on water policy with invited scholars from the Bureau of Reclamation (David Sabo from the Klamath Basin; Kim McCartney from the Yakima Basin), water law from Texas Technological University (Gabriel Eckstein), the Confederated Tribes of the Umatilla Indian Reservation (Kate Ely); the Utah State Engineer's Office (Jared Manning); as well as local mediators and NGOs.

IWW also sponsored the showing of the movie “Running Dry” to audiences in Hermiston and Pendleton, Oregon, the Oregon Water Resources Department in Salem, Oregon, and at Oregon State University in Corvallis, Oregon. Collectively, over 300 people viewed the movie and participated in a dialogue with Jim Thebaut, the director of the movie.

At the local level, IWW staff presented research on new land use reforms and groundwater use at the “Groundwater under the Pacific Northwest” conference held in Skamania, Washington. At the national level, IWW staff presented at conferences sponsored by the National Groundwater Association in Atlanta, Georgia and at the Pacific Northwest Conference in Portland, Oregon. At the international level, IWW staff was invited to present at the University of Tokyo who sponsored the session on international waters as one of the members of the Universities Partnership for Transboundary Waters.

Projects funded by IWW lead to the following presentations:

Presentations:

May 22, 2006 Eugene, Oregon. Presentation to Eugene Water & Electric Board by Gordon Grant. *Discharge, source areas, and water ages of spring-fed streams and implications for water management in the McKenzie River Basin.*

April 6, 2006. St. Cloud State University, Presentation to the Department of Earth and Atmospheric Sciences by Anne Jefferson. Five years from snowfall to spring water: Understanding the sources of streamflow in the Oregon Cascades.

March 7, 2006. University of Texas, Austin. Presentation to Jackson School of Geosciences by Anne Jefferson. Five years from snowfall to spring water: Understanding the sources of streamflow in the Oregon Cascades.

February 27, 2006 Salem, Oregon. Presentation to Army Corps of Engineers by Gordon Grant. *An Overview of the hydrology of the Willamette River System*.

January 30, 2006 Corvallis, Oregon, Presentation to Snow Hydrology class by Anne Nolin, *Climate change impacts on snow cover.*

November 17, 2005 Corvallis, Oregon. Abstract for Oregon Headwaters Research Cooperative Conference "Science and Management of Headwater Streams in the Pacific Northwest" titled *Hydrologic and Temperature Response of Cascade Headwater Streams to Projected Climate Change.*

November 3, 2005 Skamania Lodge, Washington. Presentations at CSREES annual conference - Groundwater under the Pacific Northwest by Anne Jefferson *Groundwater systems of the McKenzie River watershed, Oregon High Cascades*, and Gordon Grant *Geologically-mediated groundwater storage as a first-order control on streamflow response to changing climate in volcanic landscapes*

October 24, 2005 Dartmouth College, New Hampshire. Geology Department Seminar by Gordon Grant. *Smoldering volcanoes, secret springs, and the ultimate hydrologic sponge: Geohydrology of an active volcanic landscape.*

October 10, 2006. Corvallis, Oregon. Presentation (guest lecture) to a group of environmental journalism students by Gordon Grant. *Rivers of the Future: Effects of climate change on the hydrology of the Pacific Northwest.*

October 8, 2006. Corvallis, Oregon. Presentation to USGS Oregon Water Science Center by Anne Jefferson. Five years from snowfall to spring water: Understanding the sources of streamflow in the Oregon Cascades.

October 5, 2006. Corvallis, Oregon. Presentation to Groundwater Group by Anne Jefferson. *Five years from snowfall to spring water: Understanding the sources of streamflow in the Oregon Cascades.*

September 12, 2005, Zurich, Switzerland. Presentation by Gordon Grant. *A subterranean Lake Geneva? Volcanic landscapes as the ultimate hydrologic sponge.*

May 23-27, 2005, New Orleans, Lousiana. Presentation at American Geophysical Union Spring Meeting by Gordon Grant. *The ultimate hydrologic sponge: Hydrology and dynamics of a young volcanic arc in a mediterranean climate*

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	5	0	0	0	5
Masters	0	0	0	0	0
Ph.D.	3	0	0	0	3
Post-Doc.	0	0	0	0	0
Total	8	0	0	0	8

Notable Awards and Achievements

One of the funded projects provided a Research Experience for Undergraduates for Shawn Majors, senior, Department of Geosciences who was involved in data processing for the grant to Dr. Anne Nolin. Two Ph.D. students were also supported by the grant to Dr. Anne Nolin: Anne Jefferson, Department of Geosciences who oversaw the statistical analysis of discharge and precipitation data and was responsible for water balance calculations and Meredith Payne, College of Oceanography and Atmospheric Sciences who was involved in analysis of and interpolation snow cover data for basin-wide mapping of snow water equivalent.

Publications from Prior Projects