Water Resources Research Center Annual Technical Report FY 2008

Introduction

The major water science issue in Maryland is the health of the Chesapeake Bay. It is one of the largest economic assets in the State. Research, education, and information transfer projects of the Maryland Water Resources Research Center nearly all have a focus on the Bay and related water quality.

Research Program Introduction

With 104B funding, after peer review, the Maryland Water Resources Research Center supported two research projects and awarded two graduate student summer fellowship. All have a water quality focus and Chesapeake Bay implications.

• Microbial nitrogen sequestration in detrital-based streams of the Chesapeake Bay watershed under stress from road-salt runoff., Christopher M. Swan, University of Maryland, Baltimore County

• The biodiversity effect: Do plant species mixtures perform better than monocultures in runoff treatment wetlands? Andrew Baldwin, Department of Environmental Science & Technology, University of Maryland

• Integrated experimental and mathematical evaluation to improve the fate of the tetrachloroethene at contaminated sites—summer student research. Yen-jung Lai, Department of Environmental Science & Technology, University of Maryland

• Investigating the Fate and Persistence of dichloroacetamide herbacide safeners in model environmental systems -- summer student research. John D. Sivey, Department of Geography and Environmental Engineering, The Johns Hopkins University

Also, Maryland received funding for a 104G project: land

• "Integration of Stormwater Management Ponds into Urban Communities: Long-term Water Quality Protection, Wildlife, and Environmental Awareness." Joel Snodgrass, Towson University

Responses of Species-Rich Low-Salinity Tidal Marshes to Sea Level Rise: a Mesocosm Study

Basic Information

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Principal Investigators:	Andrew Baldwin, Peter James Sharpe

Publication

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Responses of Species-Rich Tidal Freshwater Wetlands to Sea Level Rise: a Mesocosm Study

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Introduction

Statement of Critical Regional or State Water Quality Problem

Sea level rise is threatening coastal wetlands worldwide. Increases in sea level may cause shoreward movement of salt-tolerant species such as *Spartina alterniflora* (Donnelly and Bertness 2001) or conversion of coastal wetlands to open water (Baumann et al. 1984). In the Chesapeake Bay, where the relative rate of sea level rise since 1900 has been 2.5-3.6 mm/year (Lyles et al. 1988; Stevenson and Kearney 1996), extensive marshes such as those at Blackwater National Wildlife Refuge on Maryland's eastern shore have been lost (Stevenson et al. 1985; Kearney et al. 1988). Much of the research on effects of sea level rise on coastal wetlands has focused on brackish and salt marshes, where increases in relative water level due the combined effects of land subsidence and eustatic (background) sea level rise have been implicated as a dominant factor in loss of these wetlands (Stevenson et al. 1985, 1986; Morris et al. 2002). However, little is known about the effects of sea level rise on low-salinity tidal wetlands, which include the species rich, high-productivity tidal freshwater and intermediate or oligohaline marshes (Tiner and Burke 1995). In addition to increases in water level, the salt-sensitive vegetation of low-salinity wetlands also is likely to exhibit stress or mortality due to saltwater intrusion from sea level rise (McKee and Mendelssohn 1989; Baldwin and Mendelssohn 1998). Therefore, sea level rise arguably poses a greater risk to low-salinity wetlands than to salt and brackish marshes.

The Chesapeake Bay contains one of the greatest concentrations of tidal low-salinity marshes in the United States, covering about 16,000 hectares in Maryland alone (Tiner and Burke 1995; Mitsch and Gosselink 2000). Extensive low-salinity tidal marshes are associated with many of the rivers flowing into the Bay, including the Patuxent, Choptank, Wicomico, and Pocomoke Rivers in Maryland and the James, York, and Rappahannock Rivers in Virginia (Tiner and Burke 1995). These wetlands are of tremendous importance to the Chesapeake Bay ecosystem. Due to their low salinity, the plant communities of tidal freshwater marshes are considerably more diverse than those of salt and brackish marshes. Additionally, tides and river flooding supply abundant nutrients, generating primary productivity as high as any ecosystem on earth, including agroecosystems (Tiner 1993; Mitsch and Gosselink 2000). The combination of high plant diversity and productivity and low salinity stress supports diverse and abundant fish and wildlife populations. For example, almost 300 bird species have been reported in tidal freshwater marshes, and the majority of commercially important fish species rely on tidal low-salinity wetland for some phase of their lifecycle (Odum et al. 1984; Odum 1988). These include the rockfish or striped bass, *Morone saxatilis*, a multimillion dollar fishery industry in Maryland. Reportedly 90% of east coast rockfish are spawned in the tidal fresh and oligohaline portions of tributaries of the Chesapeake Bay, where their larvae congregate in and along the edges of low-salinity marshes (Berggren and Lieberman 1977; Odum et al. 1984). In addition to supporting plants, fish, and wildlife, tidal low-salinity wetlands are used heavily for hunting, fishing, and nature observation by humans, and act to protect shoreline properties from coastal erosion and storm surges (Mitsch and Gosselink 2000).

Clearly, the loss of tidal low-salinity marshes, or their conversion to brackish or salt marshes, in the Chesapeake Bay due to sea level rise would have dramatic socioeconomic and ecological consequences. While sea level rise itself cannot be readily controlled, measures can be taken to stabilize or restore coastal wetlands. These include addition of sediment to increase elevation, a technique that has been used in coastal Louisiana to mitigate wetland loss due to sea level rise (Ford et al. 1999), and which is being considered for restoration of wetlands at Blackwater National Wildlife Refuge.

While the broad responses of vegetation to increases in salinity and soil waterlogging are understood, the potential for vegetation dieback or changes in species composition in tidal low-salinity marshes of the Chesapeake Bay and other Atlantic Coast estuaries in response to changes in salinity and waterlogging acting together has not been studied. Because of their position in the estuary, these marshes may experience increases in salinity, but not waterlogging if sedimentation patterns continue to provide adequate accretion to keep pace with increases in water level (Kearney et al. 1988). Alternatively, salinity and water level both may increase. Currently little quantitative information exists upon which to base predictions of changes in species diversity or composition in tidal low-salinity marshes, or even whether vegetation will die back under different projected sea level rise scenarios (IPCC, 2001). Because of the ecological and socioeconomic significance of tidal low-salinity marshes of the Bay and elsewhere, quantitative information and predictive models are invaluable tools for understanding how coastal wetlands will respond to increases in sea level and in designing mitigative measures or wetland restoration projects in the face of sea level rise.

Preliminary Research

During 2006 we studied patterns of plant diversity and composition across low-salinity tidal marshes in the upper estuaries of the Patuxent and Nanticoke Rivers in Maryland. Vegetation cover was described in 1000 m^2 plots located across an approximately 50-km gradient at roughly 5-km intervals, extending across tidal freshwater and oligohaline marshes into the brackish marsh zone in both estuaries. Sampling used the module method for non-destructive sampling, which combines large-scale sampling (1000 m^2) with nested plots of 100 m^2, 10 m^2, 1 m^2, 0.1 m^2, and 0.01 m^2 (Peet et al. 1998). This methodology is a powerful but rapid method that provides composition data across a relatively large area of marsh and allows comparison of species richness at different spatial scales.

Preliminary results show a species richness peak occurring in areas 15-25 km downstream from the uppermost tidal freshwater marshes. In these reaches salinity periodically increases of 2-5 ppt (mddnr.chesapeakebay.net) during periods of low river discharge, which typically occur in late summer during drought years; our springtime 2006 measurements also detected salinity (Fig. 1). This observed peak in plant species richness occurs within the fresh-brackish transition (oligohaline zone) of both rivers and

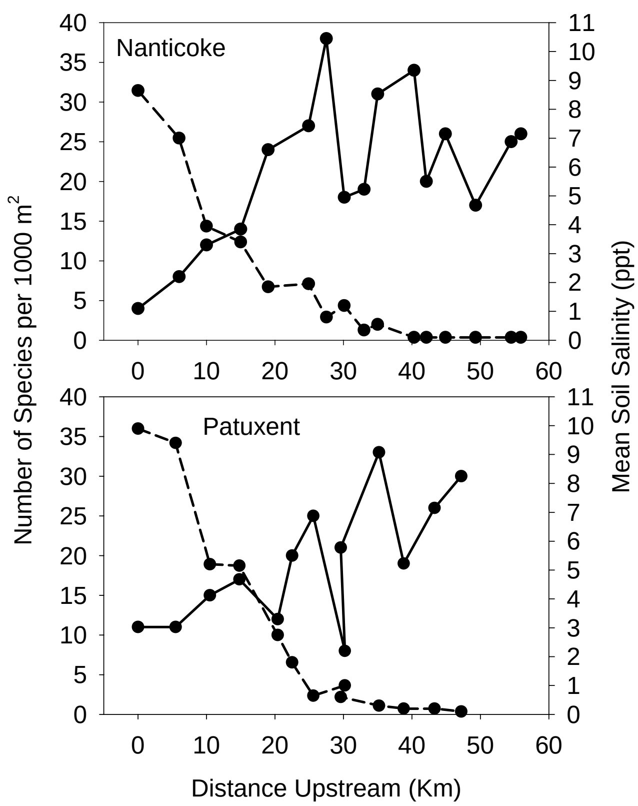

Figure 1. Plant species richness in 1000-m^2 plots (solid lines, left axis) and porewater salinity (dashed lines, right axis) in tidal marshes in the upper Nanticoke and Patuxent Rivers, Maryland (May/June 2006).

challenges the popular belief that plant species richness is uniformly and inversely related to salinity in tidal marsh ecosystems (Anderson et al. 1968; Tiner 1995; Odum 1988). We hypothesize that the principal abiotic mechanisms controlling the observed plant species richness peak is periodic salinity stress, which reduces the competitive advantages afforded many freshwater plant species and allows less competitive brackish marsh plants to survive in this transition zone.

These preliminary results document the considerably higher plant diversity in low-salinity tidal marshes and that increases in salinity associated with sea level rise will reduce the diversity of these wetlands. Furthermore, if marshes are unable to migrate landward, as is expected in many regions due to coastal steepening, the low-salinity marshes may succumb to the so-called "coastal squeeze" between saline marshes and uplands (Taylor et al. 2004).

While these preliminary findings demonstrate correlation between salinity and plant diversity in coastal wetlands, stronger cause-and-effect relationships can be examined using manipulative experiments than is possible in observational studies. Questions not addressed by this preliminary research are: 1) how do increases in salinity concentration alter species richness and composition in low-salinity coastal marshes?; and 2) does soil waterlogging, also predicted to increase due to sea level rise, reduce or interact with changes in salinity? These questions are the subject of our research.

Nature, Scope, and Objectives of the Project

Our overall goal for the research proposed here is to understand how changes in salinity and water level will influence diversity and ecosystem function of these tidal low-salinity marshes. Specifically, our objectives were to:

1) Create experimental wetland mesocosms containing species from tidal oligohaline and freshwater marshes
2) Subject mesocosms to a factorial arrangement of salinity and inundation treatments
3) Relate changes in plant communities and indices of ecosystem function to potential changes in water level and salinity predicted under various sea level rise scenarios

Through these objectives we tested the following hypotheses, developed based on literature discussed previously and later in the Related Research section:

H1: Increases in salinity will tend to reduce plant diversity (species richness and diversity index) and indices of ecosystem function (biomass, nutrient pools, and soil respiration), but maximum diversity will occur at low salinity rather than in fresh water.

H2: Increases in salinity will result in a shift toward salt-tolerant species.

H3: Increases in soil waterlogging will reduce plant diversity and growth of all species.

H4. Salinity and waterlogging will interact in a synergistic manner to reduce diversity and ecosystem function.

Methods

To examine the potential future responses of low-salinity marsh vegetation to sea-level rise, we developed a greenhouse experiment subjecting marsh mesocosms (the experimental unit) to a range of salinity and soil flooding conditions. The experiment tested the effects of various salinity and flooding regimes on species richness, species composition, and indices of ecosystem function (i.e. above and below ground biomass). Specifically, we subjected synthetic plant communities to three levels of soil flooding and five levels of salinity (0, 1.5, 3, 6, and 12 parts per thousand or ppt) in a 3 x 5 factorial treatment arrangement. For reference, the salinity of ocean water is about 35 ppt, and the salinity classification of coastal marshes is <0.5 ppt for freshwater, 0.5-5 ppt for oligohaline or intermediate marshes, 5-18 for mesohaline or brackish marshes, and >18 for polyhaline or salt marshes (Cowardin et al. 1979).

Mesocosm Configuration

Because of possible gradients in light, temperature, or humidity across greenhouse benches, as well as greenhouse space limitations, experimental units were arranged in a split-plot randomized complete block design (Figure 2). Each block represented a replicate for salinity (i.e. two replicates for salinity) this represented the whole-plot effect, with the sub-plot factor being flooding frequency and having three replicates per trough (Figure 2).

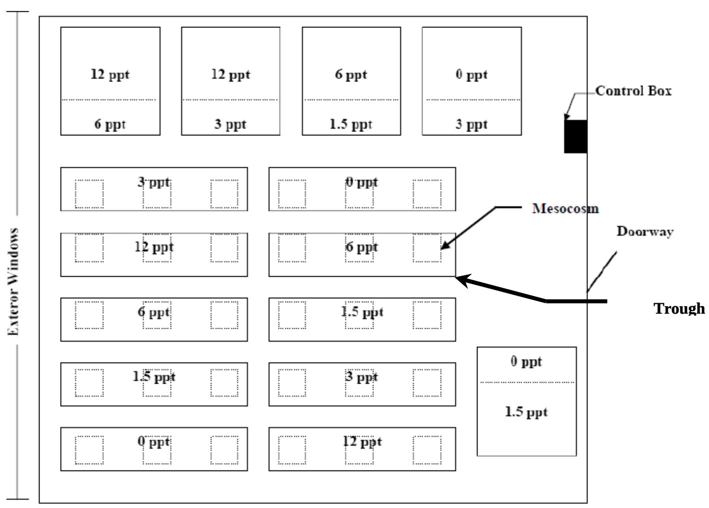

Figure 2. Plan view of experimental treatments and layout for the greenhouse mesocosm study (total experimental units = 30, salinity replicates = 2, and flooding frequency replicates = 10).

The mesocosms consisted of a container design that allowed control of water level and supply of salinity and nutrients. The mesocosm itself was a 56 x 44 x 44 cm (h x l x w; 151.4 L), Rubbermaid® Square Brute container Atlanta, GA with 16, 1.3-cm diameter perforations along the bottom to allow for exchange of water within the watering trough. Each mesocosm also had mesh screens installed at the bottom of each mesocosm over the drainage holes to prevent soil loss. The screens were made from plastic and had a 4 mm^2 mesh size. The watering troughs were made from pressure treated lumber and were (61 x 196 x 56 cm, 666 L). The troughs were designed to house three mesocosms each and were fed by a dedicated reservoir randomly assigned to that particular trough (Figure 2). The reservoirs were also constructed from pressure treated lumber and were (56 x 117 x 117 cm, 767 L) and were randomly located within the greenhouse. To prevent leaking, the troughs and reservoirs were lined with 45-mil thick black Firestone Pond liners Nashville, TN (Figures 3 and 4). Submersible pumps (Little Giant 115 Volt, Franklin Electric, Blufton, IN) were placed in the reservoirs and troughs to move water into and out of the system. The pumps were attached to a circuit board and timing mechanism set to a six hour interval rate. The circuit controller activated the pumps and allowed the reservoirs to fill over a period of 6 hours, at the end of the 6 hour cycle the system activated a second set of pumps and drained the system over a another 6 hour period. This 6 hour pumping cycle was established to simulate the natural tidal cycles of marshes within the Chesapeake Bay. Target salinity levels were achieved through the addition of Instant Ocean Sea Salt to our targeted treatment level and verified through the use of a handheld YSI-30 SCT meter.

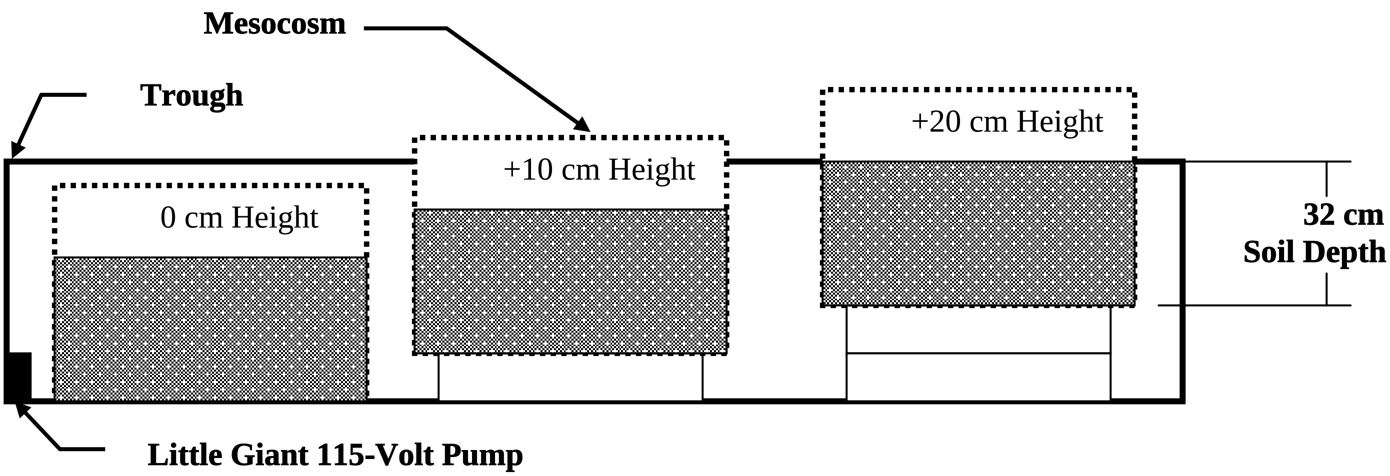

Figure 3. Profile drawing showing a conceptual layout of the marsh mesocosms within a trough.

Flooding frequencies were altered by elevating the mesocosms on concrete blocks; each mesocosm was randomly assigned a height of + 0 cm, +10 cm, or +20 cm above the trough bottom. These heights corresponded to a flood frequency (percent of hours in a 24 tidal cycle) that the soil surface was inundated with water 23%, (+20 cm), 44% (+10 cm), and 62% (+0 cm). Flooding frequencies were verified using an automatic water level (WL-15 Global Water, Inc Gold River, CA) recording device placed inside a representative trough and measured over a period of 24 hours. For reference, flooding durations measured from 29 marsh plots along the Nanticoke and Patuxent Rivers averaged 35% in 2006.

Figure 4. The lined trough and mesocosms in July 2007.

Experimental Plant Community – Mesocosm and Seedbank Studies

The goal of this experiment was to create a diverse assemblage of plant species representative of conditions across one of our previously surveyed river gradients. This goal was accomplished by inoculating the mesocosms with homogenized soils containing seeds collected along the Patuxent River marsh gradient and supplementing the seed bank with some dominant planted perennials identified previously (Chapter 2), and representative of the entire fresh-brackish salinity gradient. The rationale for including some species of brackish marsh plants was to provide a source of vegetative material that would allow plant communities to potentially shift from salt-intolerant to salt-tolerant communities if environmental conditions became appropriate, as occurs in coastal wetlands experiencing high rates of relative sea-level rise that do not convert directly to open water (Boesch et al. 1994; Perry and Hershner 1999). Previous research has used sections of marsh soil and vegetation collected intact from wetlands rather than synthetic plant communities proposed here (Baldwin and Mendelssohn 1998; Baldwin et al. 2001). However, we decided to use synthetic plant communities because we wished to assemble a diverse suite of propagules and vegetative material from a range of coastal wetland types to better understand how the diversity and composition of wetland vegetation would respond to different combinations of salinity and flooding treatments. Synthetic plant communities also have the added benefit of reducing variation between experimental units, allowing reduced numbers of replicates, and therefore greater numbers of treatment factor levels, than would be possible with more variable soil-vegetation sections.

Marsh surface soils were collected from four marsh locations (two freshwater sites, one transitional site, and one brackish site) along the Patuxent River on March 19-21, 2007. Marsh soils were collected by hand using 5 x 4.75 cm (h x d) corers. A total volume of 38 L (of the top five centimeters of topsoil) was collected from each of the four sites. An additional freshwater marsh site was needed due to concern that a sufficient number of freshwater annual plants would not germinate from a single site. As commercially grown wetland annuals are difficult to obtain, the additional fresh marsh site was included to ensure adequate representation of each salinity class in our mesocosms. The collected marsh topsoil was stored in 19 L buckets and placed in refrigerated conditions until April 17, 2007 when the soils were homogenized.

Marsh surface soil samples from each location were homogenized in a cement mixer and five (284 cm^3) samples from the homogenized soil from each site were extracted, and spread in a uniform 1-cm thick layer on top of a 2-cm thick layer of Sunshine LC1 potting soil mix within 4 x 14 x 20.3 cm (H x W x L) aluminum pans. Next the collected topsoil across all four marsh locations was homogenized by placing one bucket of topsoil from each marsh type into a cleaned and rinsed cement mixer. The cement mixer was run for seven minutes and the resulting mixture was placed back into the four empty buckets. This process was repeated for the remaining four topsoil sample buckets. Next, two buckets from each of the mixed sets were chosen haphazardly (four buckets total) and mixed again for five minutes and poured back into the empty buckets. This process was repeated for the remaining four buckets. This process of mixing and re-mixing of the collected topsoil samples was utilized to achieve a homogeneous soil mixture.

Five 284-cm^3 volumes of soil were then extracted from the homogenous mix and placed in the aluminum pans as part of the seed bank variability component of this study. This process allowed us to characterize the seed banks of the individual collection sites, as well as the homogenized seedbank that was used in all the mesocosms.

The seedbank trays were randomly placed on a misting bench in the University of Maryland Research Greenhouse Complex and emerging seedlings counted by species. Soil seed banks contain seeds of several dominant annual species in low-salinity marshes, including *Polygonum* spp., *Impatiens capensis, Bidens* spp., and *Pilea pumila* (Baldwin and DeRico 1999; Peterson and Baldwin 2004). Application of a homogeneous soil sample is an effective way to introduce these species, many of which cannot be purchased from nurseries and for which seed collection would be necessary throughout the year. We anticipated that between the planted perennials and plants recruited from the seed bank would approach stem densities similar to those of natural marshes (e.g., 250 stems/m^2 in July and 150 stems/m^2 in August; Darke and Megonigal 2003).

Upon completion of topsoil homogenization and seedbank study set-up, mesocosm containers were filled with 30 cm of SUNGRO Professional Blend potting soil and inoculated with a 2-cm thick layer of collected marsh topsoil. The resulting mesocosms were put on a freshwater drip-line irrigation system, placed outside 4 April 2007 and then moved into the greenhouse (5 May 2007) and allowed to acclimate to greenhouse conditions until 11 July 2007 when the mesocosms were placed into our tidal system. Perennial wetland plants (two inch plugs) purchased from Environmental Concern, Inc. (St. Michaels, MD) were randomly planted at each of 16 positions (2 of each) within each marsh mesocosm on May 31, 2007. The perennial plants were selected based on availability and relative indicator value from a previous study (Chapter 2). The plant species were: *Acorus calamus, Distichlis spicata, Leersia oryzoides, Spartina alterniflora, Typha angustifolia, Spartina patens, Phragmites australis, and Spartina cynosuroides*. *P. australis* and *S. cynosuroides* were grown in the greenhouse from rhizomes harvested along the Patuxent River as these two species were not commercially available. All of the aforementioned perennial species were from Maryland ecotypes and two of each species were randomly placed into each mesocosm with the exception of *S. cynosuroides*. The *S. cynosuroides* rhizomes did not successfully generate enough viable plants for more than one of that particular species to be planted per mesocosm.

Mesocosm Operation

After the May 31, 2007 perennial planting event the mesocosms were maintained on a freshwater drip line system, the planted perennials were censused and dead planted perennials were removed and replaced prior to salinity treatment initialization on July 27, 2007. Salinity was altered by creating solutions of reconstituted sea water using Instant Ocean® sea water mix. After salinity treatments began for all reservoirs (except for the two fresh water troughs), final reservoir salinities were gradually ramped up over a period of twelve days. The initial salinity treatment brought reservoir salinity concentrations up to 0.75 ppt initially; followed by increases every other day, to the final levels of 1.5, 3.0, 6.0, 9.0 and 12.0 ppt. For those treatments whose target salinities were less than 12.0 ppt, no further salts were added to the system once the target salinity level was reached, except where necessary to maintain the treatment salinity level. The salinity levels were raised gradually to avoid shocking the plant communities with high salt concentrations. Historic salinity data

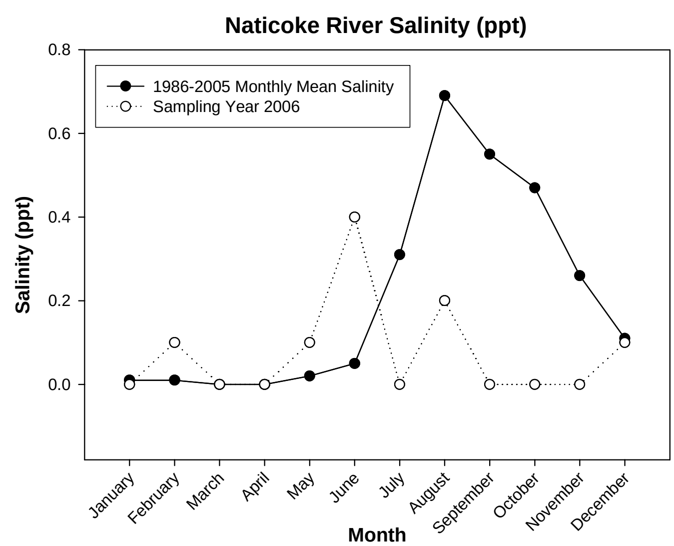

Figure 5. Nanticoke River Salinities Measured at Maryland DNR surface water quality station ET6.1 – Sharpetown, Maryland (near plot N35W) showing the mean monthly salinities measured from 1986-2005 and the mean monthly salinities from the 2006 sampling effort.

from the Nanticoke and Patuxent River (Figures 5 and 6) also show that salt concentrations tend to spike in late July and August, so this procedure was employed to mimic field conditions on these two river systems (Maryland DNR "Eyes On The Bay Program, 2007). Apart from simulating natural salinity increases, this procedure also prevented inhibition of early season germination due to salinity (Odum et al. 1984 and Baldwin et al. 1996)

The mesocosms were operated from the middle of the growing season (July 2007) to the end of July 2008. The salinities in all tanks above 0 ppt were reduced by 50% from 9 October 2007 until 1 May 2008 to simulate the seasonal retreat of the salt front from the fall through early summer. Due to evapo-transpiration losses the water within each mesocosm system was replaced, on average, once per week. Flooding regimes in the mesocosms were maintained 10 cm below the soil surface for 2 weeks so that plants could acclimate, after which water levels were adjusted to their appropriate experimental treatment condition (0cm, +10 cm, and +20 cm). This occurred concurrently with the salinity exposure.

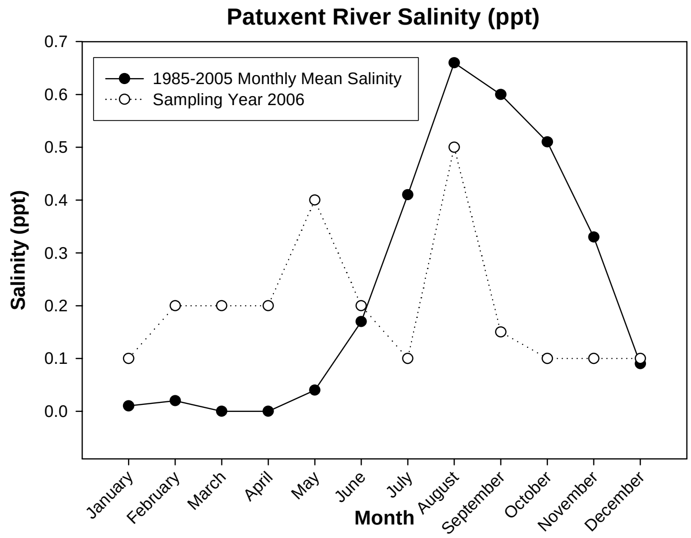

Figure 6. Patuxent River Salinities Measured at Maryland DNR surface water quality station TF1.5 at Nottingham, MD (near plot X30E) showing the mean monthly salinities measured from 1985-2005 and the mean monthly salinities from the 2006 sampling effort.

Vegetation and Environmental Measurements

Vegetation in mesocosms was censused non-destructively by using species presence/absence determinations and by estimating percent cover of each plant type using cover class from the North Carolina Vegetative Survey protocol (Peet et al. 1998). This census was performed at the beginning of the salinity/flooding treatments in June 2007, September 2007, and July 2008. The purpose of the initial monitoring was to describe variation in the initial structure of plant communities between mesocosms and track potential treatment effects within and between the mesocosms. Experimental treatment water was also periodically analyzed for salinity, pH, and temperature using YSI portable meters. Treatment water samples were also analyzed periodically for nitrate-nitrogen levels using a portable spectrophotometer (Hach 2000). Study mesocosm soils were also collected dried at room temperature, ground, and analyzed for water soluble-P (USDA 2000), Mehlich-3 extractable aluminum (Al), potassium (K), iron (Fe), calcium (Ca), and phosphorus (P). The purpose of the water and soil chemistry data collection was to identify any potential covariates that might affect the hypothesized outcomes.

At the conclusion of the experiment in July 2008, the aboveground biomass was harvested, separated by species, dried to a constant mass at 70^{o}C, and weighed. The below ground biomass was harvested by using a high pressure water hose and sieve system to separate the roots from the soil matrix. Plant roots were dried to a constant mass at 70^{o}C, and weighed.

Data Analysis

Species richness was calculated using July/September 2007 and July 2008 species count data. Shannon-Wiener diversity values were calculated using the July 2008 data. Above and below ground biomass values were analyzed separately as dependent variables using a two-way analysis of variance (ANOVA) using SAS version 9.1. Additionally, average plant species richness from 2007 and 2008 were analyzed in an ANOVA analysis against salinity and flood frequency independent variables. In instances where no significant block effects were found in the initial ANOVA analysis, the blocking factor was removed and the analysis was rerun to improve statistical power.

The environmental variables such as trough water pH, nitrate-nitrogen, and temperature were analyzed using repeated measures ANOVA analysis (proc mixed procedure) in SAS version 9.1. All soil chemistry data was analyzed using the split-plot ANOVA analysis in SAS described previously.

Non-metric multidimensional scaling (NMS) was also employed as a multivariate analysis tool for determining the relative strength of relationships between vegetation, salinity, and flooding frequency variables. The NMS analysis used a Sorenson (Bray-Curtis) distance measure with a 0.0000001 stability criterion and a maximum of 500 iterations (McCune and Grace 2002). In the NMS analysis plots were identified as Group 1-5 based on the salinity treatment for that set of mesocosms (Group 1 = 0 ppt, Group 2 = 1.5 ppt, Group 3 = 3.00 ppt, Group 4 = 6 ppt, and Group 5 = 12 ppt). NMS analysis was completed using PC-ORD Version 5.0 (MjM Software Design, Gleneden Beach, OR).

Results

Seedbank Observational Study

The results of the seedbank community study showed some significant variation in plant species richness and dominant plants between collection sites. The upper most fresh marsh community (Fresh 2) differed significantly from the brackish marsh seedbank ($p = 0.01$, Tukey adjusted) and there were no significant differences between the fresh and oligohaline seedbanks (Figure 7). As was expected the mixed seedbank, which was an amalgamation of seeds from all four sites, displayed the highest average richness, and was significantly higher then the brackish ($p < 0.01$) and lower fresh marsh site (Fresh 1) ($p < 0.01$). *Eleocharis parvula* and *Pluchea purpurascens* were the most frequently observed plant species from the brackish seedbank ($\overline{x}$ = 662 ± 83 and $\overline{x}$ = 42 ± 4 seeds/sample respectively) and the mixed community seedbank ($\overline{x}$ = 43 ± 36 and $\overline{x}$ = 12 ± 1.5 seeds/sample respectively). A total of 36 species were observed across all seedbank communities (Table 1); average frequencies for most seedbank species ranged from 1 to 20 individuals.

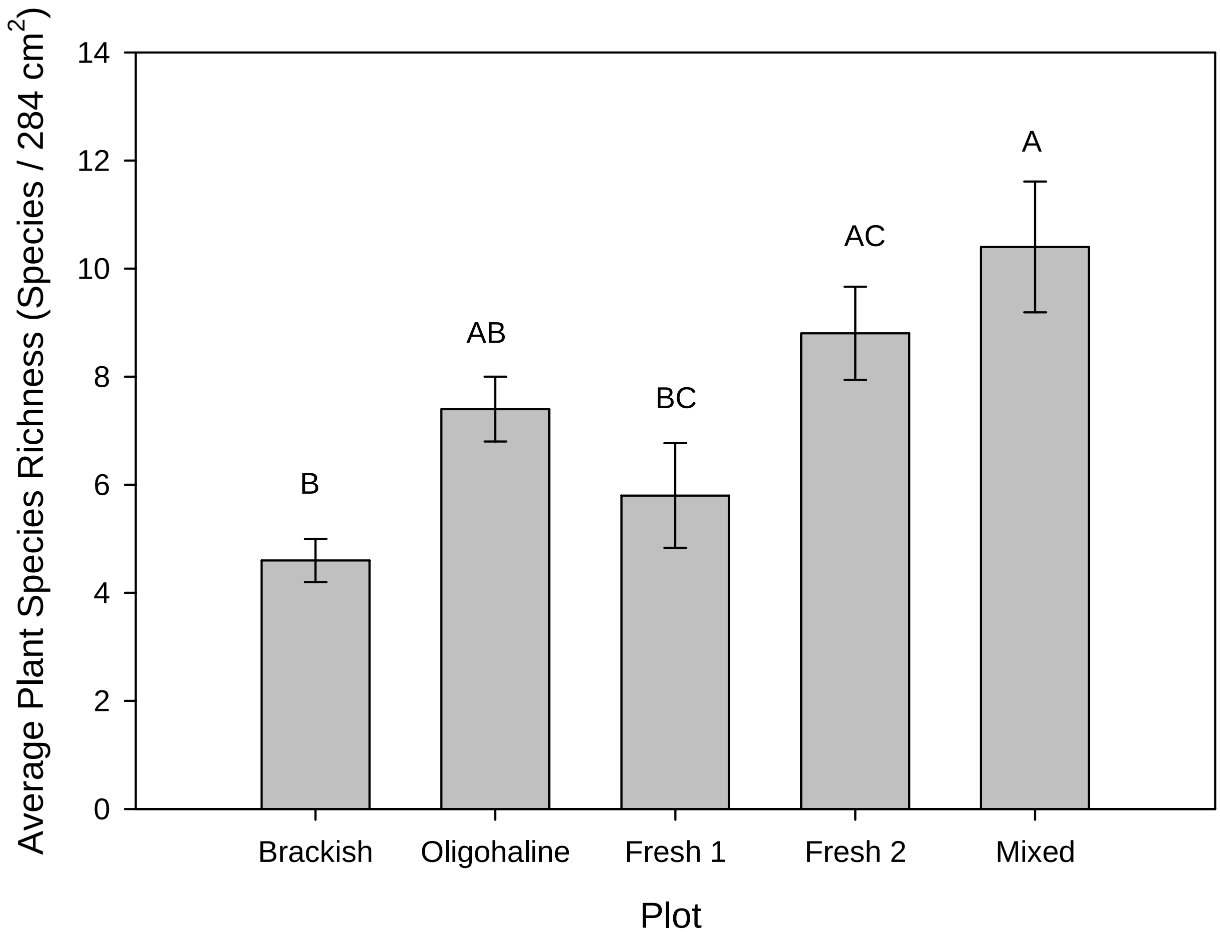
Average Plant Species Richness (Species / 284 cm2)
14
12
10
8
6
4
2
0
A
AC
AB
BC
B
Brackish
Oligohaline
Fresh 1
Fresh 2
Mixed
Plot

Table 1. Plant species observed within collected tidal marsh seedbanks along the Patuxent River (values are means, SE is the standard error).

	Fresh 2		**Fresh 1**		**Oligohaline**		**Brackish**		**Mixed**	
Species	Mean Frequency	SE	Mean Frequency	SE	Mean Frequency	SE	Mean Frequency	SE	Mean Frequency	SE
Alnus rugosa (du Roi) Spreng.			0.20	0.20						
Amaranthus cannabinus (L.) Sauer	0.60	0.24	0.20	0.20	0.20	0.20			0.60	0.24
Aster puniceus L.	1.60	0.68	0.80	0.37					0.20	0.20
Aster simplex Willd.	1.00	1.00								
Atriplex sp.							0.20	0.20		
Boehmeria cylindrica (L.) Sw.	0.80	0.49	0.60	0.24					0.80	0.37
Cardamine pensylvanica Muhl. Ex Willd.					4.60	2.60	0.60	0.40		
Cinna sp.									0.20	0.20
Cuscuta gronovii Willd. Ex Schult.	0.20	0.20	0.20	0.20						
Cyperus erythrorhizos Muhl.	4.20	0.58	0.20	0.20					2.00	0.32
Cyperus odoratus L.							0.20	0.20		
Cyperus spp.	0.20	0.20	0.20	0.20						
Echinocloa sp.	0.20	0.20					0.20	0.20	0.20	0.20
Eleocharis parvula (Roem. & Schult.) Link ex Bluff, Nees & Schauer	0.40	0.40	8.60	8.60			662.80	82.58	43.60	36.28
Hibiscus moscheutos L.					0.40	0.24				
Iva frutescens L.							3.00	1.95	0.40	0.24
Juncus effusus L.	0.20	0.20								
Kosteletzkya virginica (L.) Presl			0.20	0.20						
Leersia oryzoides (L.) Sw.	2.40	0.60			5.20	0.80			1.40	0.24
Lobelia cardinalis L.									0.20	0.20
Lythrum salicaria L.					0.80	0.49				
Mentha arvensis L.									0.20	0.20

Species	Fresh 2 Mean Frequency	SE	Fresh 1 Mean Frequency	SE	Oligohaline Mean Frequency	SE	Brackish Mean Frequency	SE	Mixed Mean Frequency	SE
Pilea pumila (L.) A. Gray	7.00	1.38	6.20	1.36	0.40	0.24			3.40	1.30
Pluchea purpurascens (Sw.) DC.	0.20	0.20			0.80	0.37	42.20	4.44	12.00	1.58
Polygonum arifolium L.	0.20	0.20			0.20	0.20			0.40	0.24
Polygonum punctatum Elliot					1.40	0.40				
Polygonum sagittatum L.			0.20	0.20						
Sagittaria latifolia Willd.	0.20	0.20								
Schoenplectus fluviatillis (Torr.) M.T. Strong									0.20	0.20
Schoenplectus robustus (Pursh) M.T. Strong							1.00	1.00		
Schoenplectus tabernamontani (C.C. Gmel.) Palla	1.00	1.00	1.40	1.40	2.00	2.00				
Spartina cynosuroides (L.) Roth					0.60	0.40	0.20	0.20	0.80	0.80
Spartina patens (Aiton) Muhl.							4.80	4.55		
Teucrium sp.					0.40	0.40				
Typha angustifolia L.			0.20	0.20						
Typha spp.	0.80	0.37	1.40	0.60	1.40	2.59			2.40	0.93

Mesocosm Study

Data were originally analyzed as a block design, but the block effect was not significant, therefore it was removed from the model. The results of the overall split plot ANOVA supported our initial hypothesis regarding the impact of salinity on plant species richness, specifically that salinity would create significant differences in low versus high salinity treatment mesocosms (Table 2). This is also supported by the clear trend observed in the July 2008 mesocosm richness data that show a clear downward trend in richness between the low-salinity oligohaline mesocosms (1.5 ppt) and the most saline treatment mesocosms (12 ppt) (Figure 8). Flooding frequency and the interaction between flooding frequency and salinity effects were also not significant, which was contrary to our original hypothesis that flooding has a strong influence on tidal marsh plant diversity.

Table 2. Overall Type III Test of Fixed Effects using plant species richness (July 2008) as the response variable and salinity, flooding frequency, and salinity*flooding frequency as independent variables. Richness values are from species counts per mesocosm.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Salinity	4	15	6.01	0.0043
Inun (Flooding Frequency)	2	15	1.79	0.2016
Salinity*Inun	8	15	0.54	0.8057

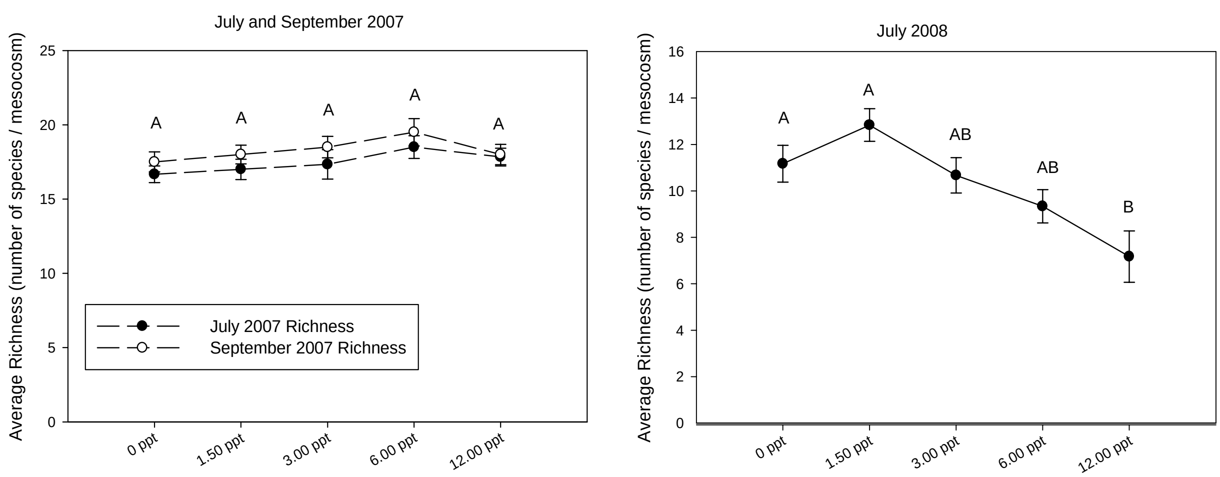

Figure 8. Mesocosm plant species richness during the initial portion of the experiment (2007) and following one entire year of salinity treatments (July 2008). Bars depict mean plant species richness based on salinity treatment group with standard error bars and significant differences depicted. Means with different letters are significantly different with each date (Tukey's HSD, p <0.05). Richness values are from species counts per mesocosm.

These results of the July 2008 richness data differ from the preliminary findings of this study in 2007 which found no significant differences in plant species richness between salinity treatments at either the initial (June 2007) or late growing season (September 2007) plant surveys. Additionally, mean plant species richness within all of the mesocosms showed a marked decline between 2007 and 2008 (Figure 11). This was likely due to little or no influx of seeds from 2007 to 2008 and no cold stratification within the greenhouse environment between growing seasons. However, exposure of seedlings to elevated salinity levels early in the growing season of 2008 produced trends in the low-salinity oligohaline (1.50 ppt) mesocosms similar to those observed along the Nanticoke River in 2006 (see Figure 1 and Chapters 1 and 2). The observed trend in the July 2008 data in Figure 11 was also the same as the Nanticoke River data in that the low-salinity (1.5 ppt) mesocosm community had a average richness values comparable (not significantly different) to the fresh marsh community. As in Chapter 2 this difference was not significant at the 0.05 level. Additionally, average Shannon-Wiener indices of plant species diversity across all salinity treatments yielded no significant differences (Figure 9).

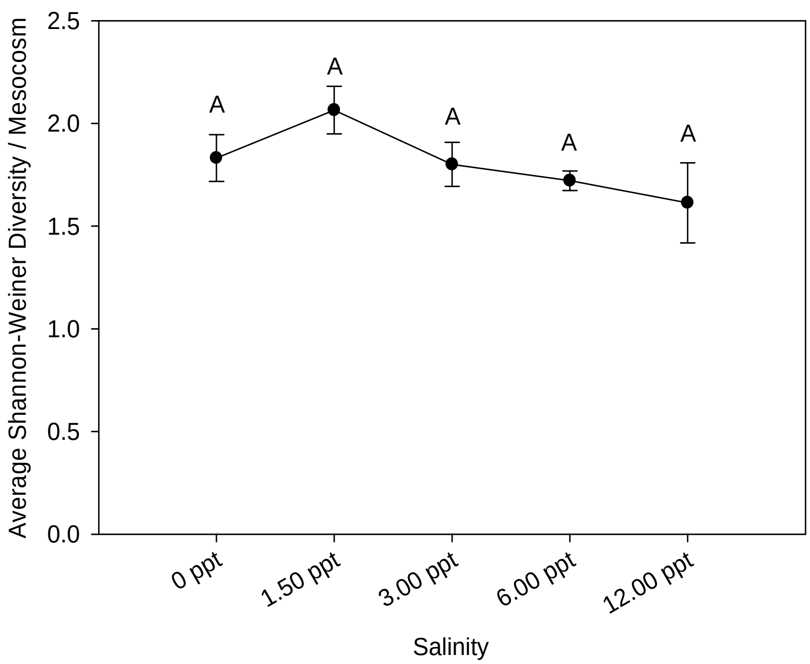

Figure 9. Average Shannon-Wiener Diversity (± SE) based on the July 2008 biomass data. Means with different letters are significantly different (Tukey's HSD, $p < 0.05$)

No significant differences with regards to plant species richness were observed between flooding frequency treatments (Figure 10).

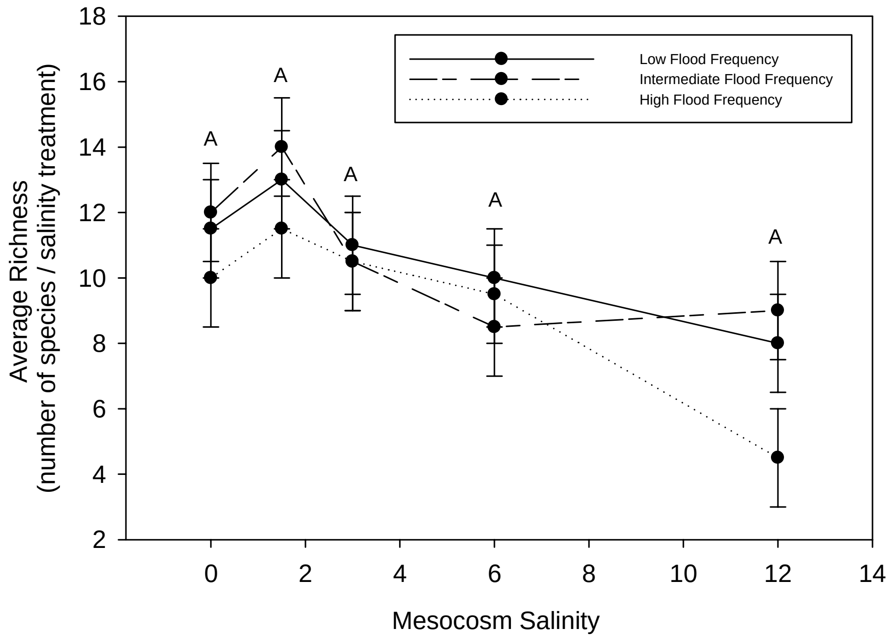

Figure 10. Average mesocosm plant species richness values based on the July 2008 biomass data and separated out by flood frequency to show potential interactions and trends. Means with different letters are significantly different (Tukey's HSD, $p < 0.05$)

Several species of plants did not regerminate and grow between the 2007 and 2008 sampling years, some of these species included *Apios americana*, *Bidens laevis*, *Cyperus esculentus*, and *Zizania aquatica* (Table 3). Additionally, species such as *Amaranthus cannabinus*, which was a dominant plant throughout many of the marsh mesocosms in 2007 based on aerial cover ($\bar{x}$ = 45 - 35% from 29 mesocosms), was present for final sampling in July 2008, but had a much lower presence and cover value ($\bar{x}$ = 15% from 5 mesocosms). Species such as *Iva Frutescens*, *Rumex* sp., and *Samolus parviflorus* were not observed in 2007 but volunteered in 2008. Of the plant species observed in the mesocosms in September 2007 80% (31 species) of them grew from the seed bank of the mesocosms, with the remaining 20% (8 species) being species which we planted randomly within each mesocosm. The July 2008 plant species list shows a 75% recruitment of plant species from the seedbank (24 species), there was also a slight drop in the total number of species between September 2007 (39 species) and July 2008 (32 species), as well as a minor drop in total cover following treatments (Table 3).

Table 3. Mesocosm mean plant species cover and standard errors for June and September 2007, and July 2008. Mean species cover was averaged across all 30 mesocosms.

Species	**Mean Cover June 2007**	**Mean Cover September 2007**	**Mean Cover July 2008**
Acorus calamus L.	1.76 +/- 0.21	3.65 +/- 0.79	1.63 +/- 0.43
Amaranthus cannabinus L.	44.82 +/- 4.32	35.36 +/- 3.63	16.88 +/- 3.71
Apios americana Medic.	1.5 +/- 0.00		
Aster puniceus L.	0.5 +/- 0.00	3 +/- 0.46	9.9 +/- 1.30
Atriplex sp.			
Bidens laevis L.	17.5 +/- 0.00	29.17 +/- 5.35	
Bidens sp.		0.50 +/- 0.00	
Bidens coronata (L.) Britt.	24.17 +/- 2.11		
Boehmeria cylindrica (L.) Sw.	0.50 +/- 0.00	3 +/- 0.55	8.83 +/- 1.48
Cinna sp.		0.5 +/- 0.00	1.17 +/- 0.11
Cuscuta gronovii Willd.	2.93 +/- 1.48	3.21 +/- 0.48	
Cyperus sp.		1.83 +/- 0.28	
Cyperus strigosus L.		1.5 +/- 0.00	13.11 +/- 2.59
Cyperus esculentus L.	0.5 +/- 0.00	1.83 +/- 0.28	
Cyperus filicinus Vahl		1.5 +/- 0.00	
Decodon verticillatus (L.) Ell.		0.5 +/- 0.00	
Distichlis spicata (L.) Greene	7.5 +/- 0.00	2.27 +/- 0.69	4.07 +/- 1.36
Echinochloa muricata (Pursh) Nash			9.43 +/- 2.80
Echinochloa walteri (Pursh) Nash	17.39 +/- 2.40	28.77 +/- 3.75	
Eleocharis parvula (R.&S.) Link			1.8 +/- 0.44
Galium tinctorium L.	0.5 +/- 0.00	0.75 +/- 0.09	2 +/- 0.39
Galium palustre L.	0.5 +/- 0.00	0.5 +/- 0.00	
Hibiscus moscheutos L.		7.5 +/- 0.00	
Hibiscus sp.	2 +/- 0.39	5.5 +/- 0.52	
Impatiens capensis Meerb.	7.5 +/- 0.00		
Iva frutescens L.			1.5 +/- 0.00
Juncus effusus L.			0.5 +/- 0.00
Juncus sp.		0.5 +/- 0.00	
Kosteletzkya virginica (L.) Presl		1.5 +/- 0.00	13.5 +/- 1.15
Leersia oryzoides (L.) Sw.	16.03 +/- 0.70	28.2 +/- 3.15	26.99 +/- 4.50
Lythrum salicaria L.	0.5 +/- 0.00	3.5 +/- 0.00	8.5 +/- 1.21
Mikania scandens (L.) Willd.	0.74 +/- 0.14	19.07 +/- 2.06	40.85 +/- 4.55
Murdannia keisak (Hasskarl) Hand.-Mazz	0.5 +/- 0.00	2.5 +/- 0.51	2.15 +/- 0.47
Nasturtium offiicinale R. Br.	7.3 +/- 1.03		
Peltandra virginica (L.) Schott & Endl.	1.86 +/- 0.82	1.33 +/- 0.21	0.23 +/- 0.04
Phragmites australis (Gav.) Trin.	3.1 +/- 0.67	9.35 +/- 1.43	27.47 +/- 3.10
Pilea pumila (L.) Gray	28.05 +/- 2.65	16.95 +/- 2.24	0.55 +/- 0.12
Pluchea purpurascens (Sw.) DC.	33.5 +/- 2.72	8.73 +/- 1.16	14.69 +/- 3,14
Poaceae sp.			7.5 +/- 0.00
Polygonum arifolium L.	41.39 +/- 3.70	19.75 +/- 2.80	0.5 +/- 0.00

Species	Mean Cover June 2007	Mean Cover September 2007	Mean Cover July 2008
Polygonum punctatum Ell.	16.34 +/- 2.00	18.83 +/- 2.25	
Polygonum sagittatum L.	5.23 +/- 0.73	4.5 +/- 0.37	
Polygonum sp.	7.5 +/- 0.00		
Rorippa islandica (Oeder) Borbas	0.5 +/- 0.00	0.5 +/- 0.00	
Rumex sp.			8.17 +/- 1.48
Samolus parviflorus Raf.			8.42 +/- 1.53
Schoenplectus sp.	0.5 +/- 0.00		3.13 +/- 0.59
Senecio sp.	0.5 +/- 0.00		
Sonchus sp.	17.5 +/- 0.00		
Spartina alterniflora Loisel.	7.5 +/- 0.00	2.23 +/- 0.65	0.06 +/- 0.05
Spartina cynosuroides (L.) Roth	1.3 +/- 0.26	2.5 +/- 0.38	5.05 +/- 0.90
Spartina patens (Ait.) Muhl.	7.5 +/- 0.00	6.3 +/- 1.04	19.75 +/- 4.00
Typha angustifolia L.	0.5 +/- 0.00	0.68 +/- 0.07	1.34 +/- 0.37
Zizania aquatica L.	12.5 +/- 1.29	7.5 +/- 0.00	
Unidentified Dicot		0.5 +/- 0.00	0.1 +/- 0.00
Unidentified Dicot 2			0.1 +/- 0.00
Total Species Count	**37**	**39**	**32**
Total Cover	**339.91**	**285.77**	**259.84**

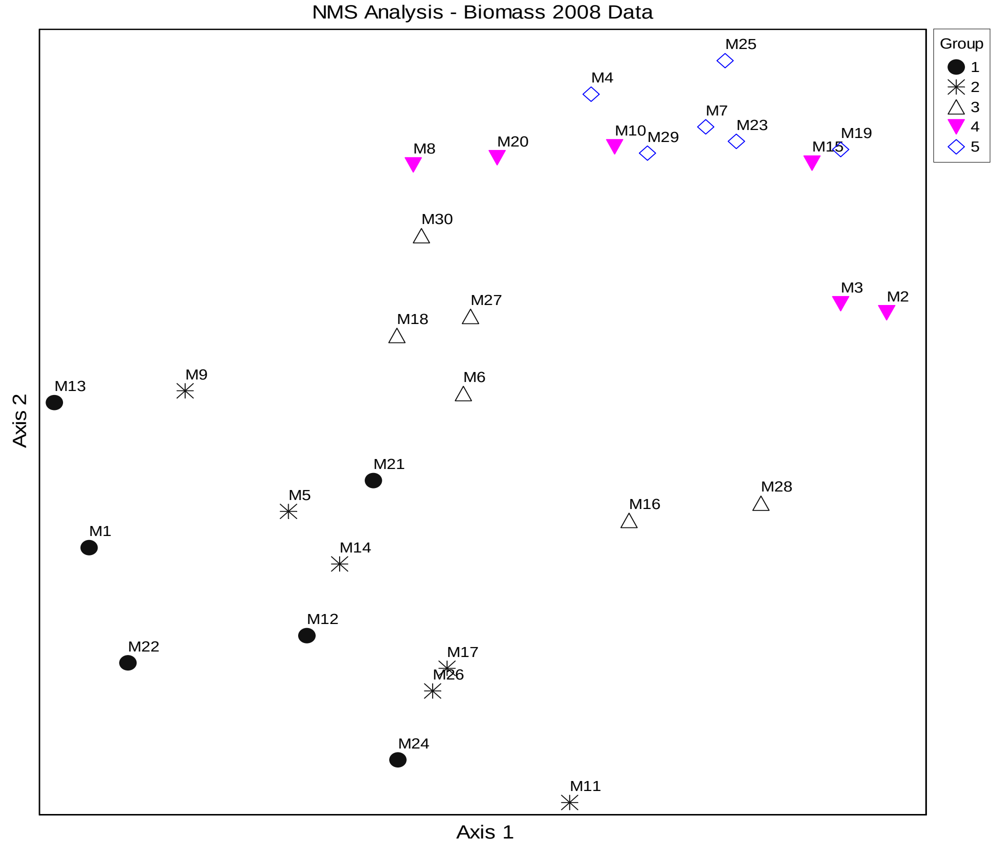

Figure 11. NMS two dimensional graph showing the mesocosm biomass data, individual points are mesocosms from the final harvest in July 2008. The groups are arranged by salinity treatment with Group 1 = 0 ppt, Group 2 = 1.5 ppt, Group 3 = 3 ppt, Group 4 = 6 ppt, and Group 5 = 12 ppt. Points are individual mesocosms.

Not only were there observed changes in individual plant species occurrence and abundance between 2007 and 2008, but there was also a strong shift in the plant species communities themselves in response to the salinity treatments. Figure 11 shows an NMS graph of the mesocosm species biomass from July 2008 relative to salinity and flooding. Clear patterns in the plant communities shown by distinct clustering of mesocosms arranged by salinity treatment can be readily observed. These results suggest that over the course of the 2007-2008 year the plant communities began to shift in response to the treatments, with fresh water marsh species doming minatin low-salinity ranges and salt tolerant species dominating in the high salinity mesocosms. This outcome supports the hypothesis of plant community shifts in response to the salinity treatments. Differences in the above ground biomass of the ten most abundant plant species based on biomass and frequency of occurrence within study mesocosms also varied as a function of salinity. Fresh marsh plant species such as *Mikania scandens*, *Cyperus* sp.1, and *Leersia oryzoides* displayed higher biomass in the low-salinity ranges of the experiment (0-1.5 ppt) and a general decline in biomass as salinity increased. *Phragmites australis* and *Spartina cynosuroides*, two species common in oligohaline-brackish marshes along the Patuxent and Nanticoke Rivers, showed no pattern of biomass differences across the salinity range (0-12 ppt) (Figure 15). *Spartina patens* had higher average biomass in mesocosms exposed to salinity treatments ranging from 6-12 ppt in 2008. Fresh marsh plant species such as *Mikania scandens*, *Cyperus* sp.1, and *Leersia oryzoides* displayed higher biomass in the low-salinity ranges of the experiment (0-1.5 ppt) and a general decline in biomass as salinity increased.

Phragmites australis and *Spartina cynosuroides*, two species common in oligohaline-brackish marshes along the Patuxent and Nanticoke Rivers, showed no pattern of biomass differences across the salinity range (0-12 ppt) (Figure 12). *Pluchea purpurascens and Kosteletzkya virginica*, two species also found in oligohaline-mesohaline marshes showed distinct peaks at 3 and 6 ppt respectively. As the graphs in Figure 12 only show the average plant biomass/salinity treatment, it's possible that at extreme fresh water and salt water conditions the combination of salinity and flooding frequency at one end, versus competition and flooding at the other imparted restrictions on these species distributions and caused their peak biomass to occur near the middle of the salinity range.

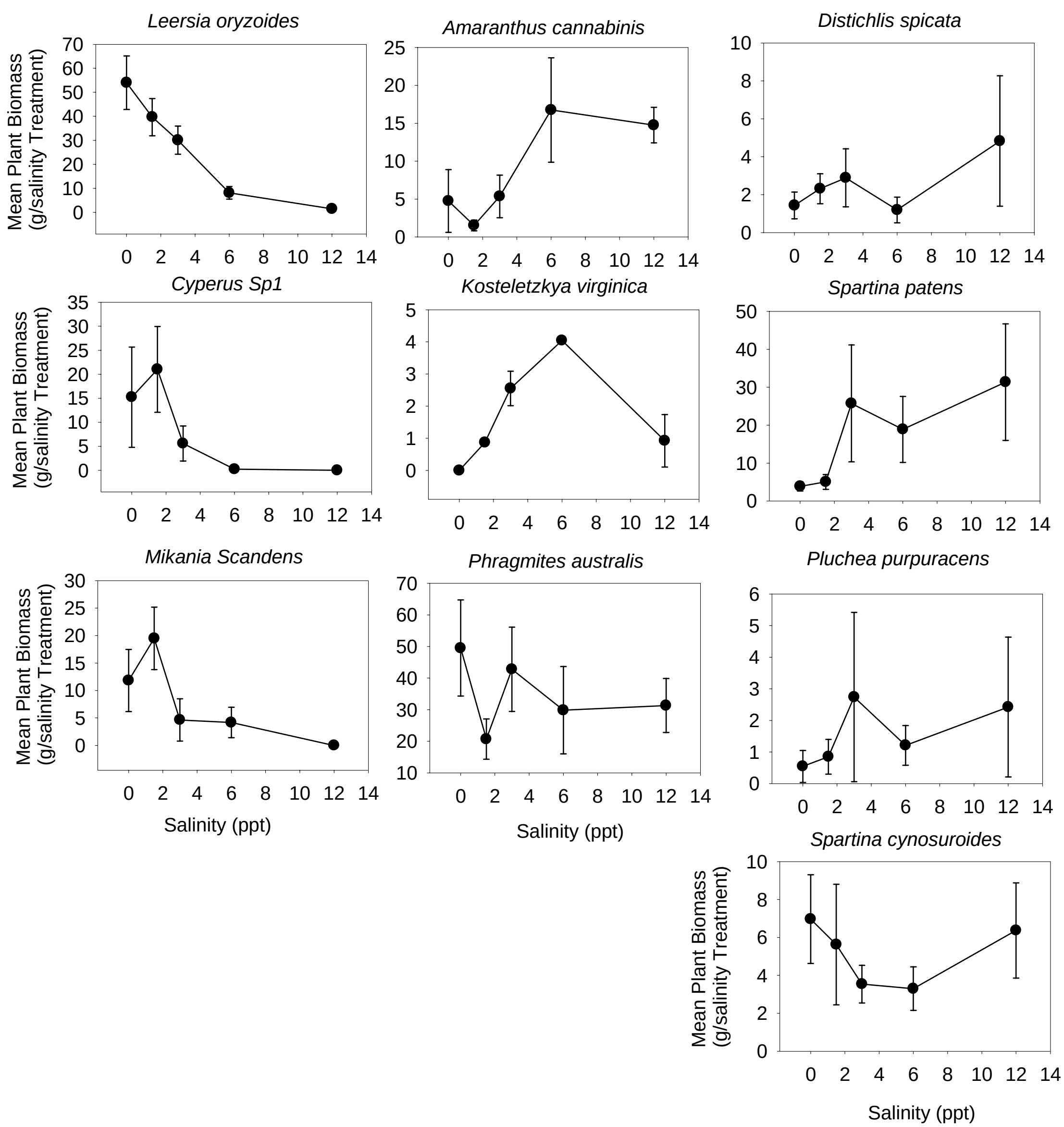

Figure 12. Graphs showing the above ground biomass (g/salinity treatment) of the ten most abundant plant species from the July 2008 biomass data from all 30 mesocosms. Individual points represent mean species biomass per salinity treatment ± SE.

Mesocosm Chemistry

No significant differences in the water soluble-P or in water nitrate-nitrogen levels were observed between treatment groups. Significant differences in average Mehlich-3 extractable magnesium, potassium, and calcium levels were observed with the high salinity mesocosms (12 ppt) having higher magnesium and potassium concentrations in the soil compared to the 0 ppt and 1.5 ppt mesocosms. Mean calcium levels were significantly higher in the purely fresh water (0 ppt) mesocosms compared to the higher salinity level treatments which was likely due to calcium precipitating out in the high salinity mesocosms as $CaSO_4$. These elemental differences were not unexpected as the Instant Ocean mix contains these micronutrients and was added to the water supply of all the salt treated tanks. There were no significant differences in average mesocosm porewater pH which ranged from 6.08 to 6.97. A significant overall difference ($p = 0.0002$, $F_{9,306}=3.69$) was observed between trough water temperatures (Figure 13).

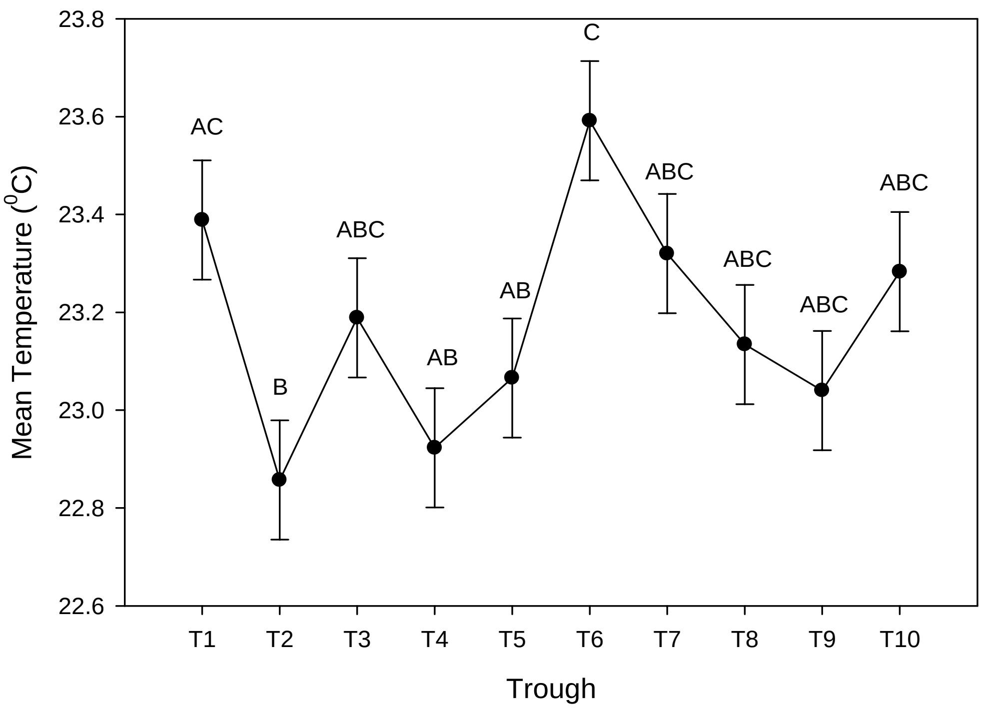

Figure 13. Average trough water temperatures measured at 35 different times over the course of the experiment (2007-2008). Means which share a letter are not significant at the 0.05 level.

Though these data show significant differences between some of the experimental trough water temperatures, it's unlikely that these differences are significant at a biological level as the difference between the highest mean temperatures (Trough 6 – 23.59 ^{0}C) and the lowest mean temperatures (Trough 2 – 22.85^{0}C) was less than 1^{0}C during the growing season.

Biomass

Our initial hypothesis was that above and below ground plant biomass would be significantly higher in the marsh mesocosms subjected to lower salinity and flood frequency disturbances. The results of the ANOVA analysis found no significant differences in mean above ground biomass across salinity and flood frequency treatment levels for the study mesocosms at the 0.05 level (Figure 14). These results coupled with the NMS output (Figure 11) and individual species biomass graphs (Figure 12) suggest that as some species are eliminated with increasing salinity they are replaced by salt tolerant species (assuming seed or propagule material is available). This replacement of species helps offset the loss of biomass in the marsh mesocosms. Mean above ground biomass among salinity treatments separated out by flooding frequency shown in Figure 15 also show no significant differences between salinity treatments.

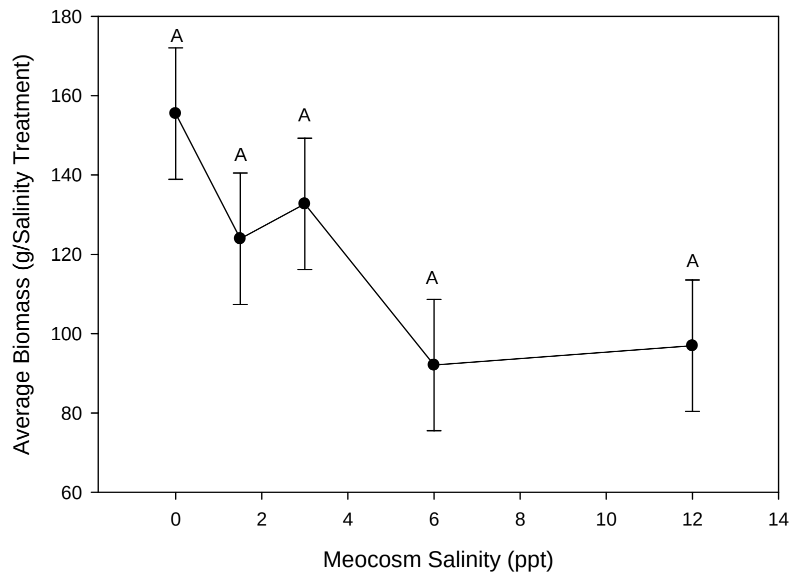

Figure 14. Mean above ground biomass versus salinity for the five salinity groups. Different letters designate significant differences values are salinity group means (n=6) ± SE.

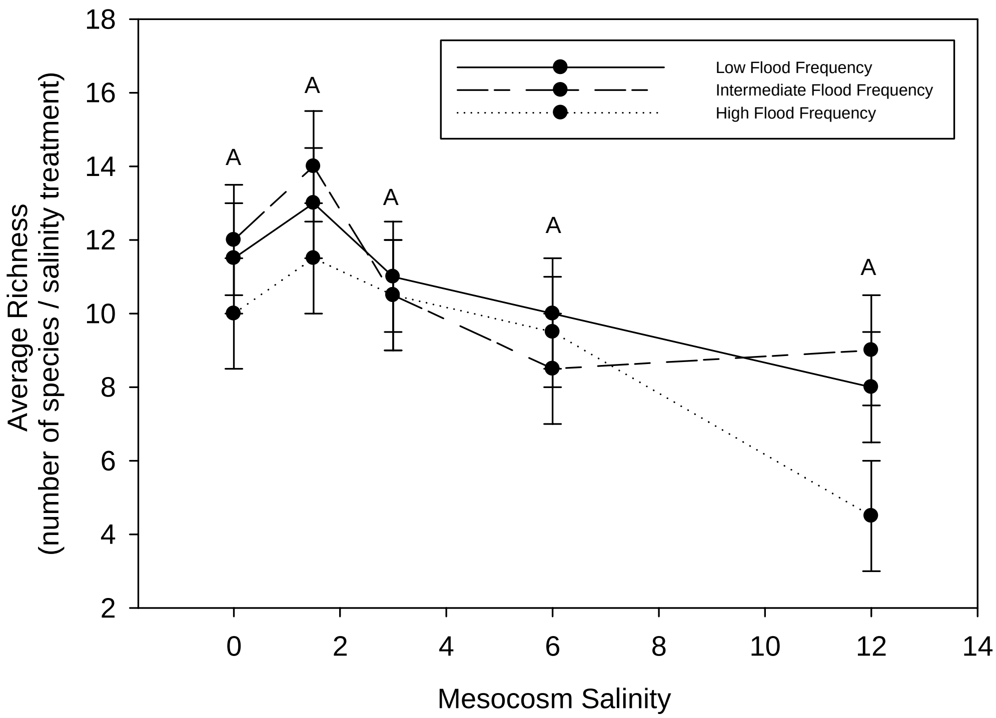

Figure 15. Mean above ground biomass versus salinity group for the three flooding treatments using July 2008 mesocosm biomass data.

Mean below ground biomass (July 2008) versus salinity treatment for the three flooding treatments displayed no significant statistical differences between these means that is consistent with the above ground biomass data in Figure 14 and suggests that the more saline tolerant species were able to minimize the impacts of increased salinity and flood frequency on the marsh mesocosms.

Discussion

Considerable research has been conducted on how salt and brackish marshes will respond to sea-level rise (Mitsch and Gosselink 2000; Morris et al. 2002; Turner et al. 2004). Much of this research has focused on the ability of salt marshes to accrete vertically at sufficient rates to keep pace with sea-level rise and the role of macrophytes in marsh stability or loss (Kearney et al. 1994; Roman et al. 1997; Day et al. 1999), or on the responses of marsh vegetation to increases in salinity and water level or soil waterlogging (Mendelssohn et al. 1981; Pezeshki et al. 1993; Broome et al. 1995; Naidoo et al. 1997; Gough and Grace 1998). These and other studies have demonstrated the importance of mineral sediment and organic matter deposition, which are critical to maintaining elevation (Reed 1995), and tolerance of marsh vegetation to increases in salinity and water logging (Kozlowski 1997). In general, growth and survival of salt and brackish marsh vegetation is reduced by increases in soil waterlogging, such as those that may occur due to sea-level rise (e.g., Webb et al. 1995; Mendelssohn and Batzer 2006). Loss of salt and brackish marshes in areas such as the Mississippi River delta plain (Louisiana) and the Chesapeake Bay is believed to primarily be the result of an inability of marsh elevation to keep up with relative sea level, which increases soil waterlogging and anoxia, stressing or killing salt marsh plants (Stevenson et al. 1985; Boesch et al. 1994).

In contrast to salt and brackish marshes, responses of tidal low-salinity marshes to sea-level rise have received little attention, with the exception of those in the Louisiana delta plain. Research in Louisiana has shown that increases in salinity, as well as soil waterlogging, due to high rates of relative sea-level rise result in vegetation dieback and wetland loss (McKee and Mendelssohn 1989; Boesch et al. 1994; Flynn et al. 1995; Webb and Mendelssohn 1996). These findings suggest that low-salinity marshes in other estuaries are similarly sensitive to increases in both relative water level and salinity. In the Chesapeake Bay, Kearney et al. (1988) found that marsh losses in the Nanticoke River estuary since the 1920s had occurred primarily in the lower portions of the estuary; tidal freshwater marshes remained relatively stable, probably because they occur in the sediment-trapping portion of the estuary. However, it is likely that as sea level rates continue to accelerate, the salt wedge and the zone of major sediment deposition will move farther upstream (Meade 1972; Officer 1981), resulting in vegetation dieback or conversion to salt-tolerant species.

The overall goal of this research was to understand how changes in salinity and water level influenced diversity and ecosystem function of tidal marsh communities grown in a controlled greenhouse environment. Our preliminary research hypothesis was that marsh mesocosms subjected to increased salinities and flood frequencies would display diminished plant species richness, diversity, and productivity with an associated shift to fresh marsh plants at low salinities and brackish marsh plants at the high end of the spectrum. Additionally, we were curious as to whether or not average plant species richness would be highest in mesocosms subjected to low oligohaline (0.75-1.50 ppt) salinity conditions similar to the pattern observed in the Nanticoke River (Chapter 2).

Salinity and Tidal Marsh Plant Species Richness

The preliminary species richness and plant community data collected in June and September 2007 showed no significant differences based on the main effects of salinity and flood frequency. Additionally no significant shifts in the plant communities from the initial mixtures were observed between June and September 2007. The results in 2007 were contrary to our research hypothesis, however, this was likely due to salinity and flooding treatments not being initiated until July of 2007 which allowed the plants to establish themselves and grow undisturbed for three months prior to treatment. Changes to the salinity and flooding regimes within the mesocosms are likely to have less of an effect on vegetation that has already become established and thus more resistant to environmental perturbation.

Plant species community data from the second year (2008) following seedling exposure to salinity and flooding treatments yielded results more consistent with our research hypothesis. However while average plant species richness was highest in the low-salinity oligohaline marsh mesocosms (0.75 – 1.50 ppt), it was not significantly different than purely fresh marsh mesocosms. This finding supports the results from Chapter 2 regarding the similarity in pattern between the low salinity mesocosms in the experiment and Our observed findings from the Nanticoke River in 2006. It would appear from Our observations and this experiment that plant species richness/diveristy along some estuarine systems can be more accurately described by a sigmiodal response to salinty rather than a simple linear relationship.

Ecological modeling determined that salinity and inundation frequency were more important overall than the MDE (Chapter 3). Therefore, we hypothesized that the observed pattern in plant species richness was the result of periodic salt water intrusions into low-salinity marshes, which suppressed the more competitively dominant fresh marsh plants, and allowed the salt tolerant species to survive and grow promoting high plant species richness/diversity. The results of this experiment which removes the influence of the MDE by mixing all short and large range species together, support this hypothesis and suggest that low-salinity oligohaline marshes may have plant species richness and diversity values equal to or sometimes even higher than purely tidal fresh water marshes. These findings lend further support to the theory of a more complex pattern of plant species richness along estuarine gradients which is contrary to the general trend of decreasing richness with increasing salinity noted widely elsewhere (Anderson et al. 1968, Odum 1988, Mitsch and Gosselink 2000, Greenberg et al. 2006).

Elevated Flooding and Salinity Effects on Tidal Low-Salinity Marshes

This research suggests that tidal marsh plant communities continuously exposed to salinities as high as 12 ppt with a concurrent increase in flooding frequency midway through the growing season are somewhat resilient to perturbation, provided the plant community is well established prior to disturbance. However, continued exposure to elevated salinity and flooding frequencies (particularly early in the growing season) caused a shift in the plant community types from more fresh-marsh plants to more brackish-marsh plants. Based on direct observation and statistical analysis of the harvested biomass it appears that the plant communities were able to convert to more mesohaline systems without a significant diminishment in biomass, provided that a source of seed/propagules of salt/flood tolerant species were available.

Implications

These findings suggest that low-salinity tidal marshes subjected to increases in flooding and salinity can maintain vegetation albeit with reduced plant biomass (at least initially), provided that they have a diverse enough assemblage of salt and flood-tolerant species in the seedbank or as available rhizome material. One plant species that seemed particularly adapt at surviving and growing under our range of salinity and flooding treatments was *Phragmites australis*. In general this plant did not show a significant diminishment in biomass across the salinity range, except under extreme flooding and salinity treatments. Given that *Phragmites australis* is a C3 plant, can propagate from seed or rhizome material, and can tolerate high flooding and salinity conditions it is already well adapted for marsh growth under elevated atmospheric carbon dioxide, salinity, and flooding conditions. Additionally, despite many efforts to remove or limit this plant species from tidal marshes within Chesapeake Bay, it still remains prevalent throughout much of the Bay ecosystem. We suggest that natural resource managers and agencies interested in restoring and protecting tidal marsh ecosystems without using invasive plants such as *Phragmites australis* focus on selecting species with similar physiological traits, as current climate model trends in Chesapeake Bay suggest an increase in salt intrusions into estuarine river systems and continual increases in relative sea-level rise (Hayhoe et al. 2007, Pyke et al. 2008).

As tidal marshes face increasing threat from anthropogenic forces, sea-level rise, and invasive plant species, understanding the principal mechanisms affecting species richness has become increasingly important. Resource managers intent on maintaining tidal marsh plant species diversity with the goal of providing ecosystem services such as high habitat diversity for wildlife should focus their efforts on low-salinity oligohaline marshes as well as on tidal freshwater systems. Invasive species such as *Phragmites australis*, though viewed by many in the natural resource community as undesirable, may be able to offer insights regarding plant selection and management of restored tidal marsh ecosystems. Our hope is that this research can be utilized to predict tidal marsh community changes over time and develop additional controlled experiments examining plant community responses to altered physical and biotic conditions, such as those caused by global climate changes.

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APPENDIX A
EXPERIMENT PHOTOGRAPHS

Photograph showing a 19 liter bucket filled with collected marsh topsoil

Marsh mesocosms in May 2007 prior to experimental treatments

Randomly planting supplemental plant species not recruited from the seedbank May 31, 2007

Marsh mesocosms in July 2007 just before the start of treatments

Timing box and relay switchboard for controlling the flow of water into and out of the mesocosm troughs

View of the marsh mesocosms in July 2007.

View of the marsh mesocosms at high tide in May 2008. Water level treatment effect is visible.

Peter Sharpe giving a presentation on the mesocosm experiment to group of graduate students from the University of Hamburg, Germany (August 2008).

Assessing the role of road salt run-off on the critical ecological interactions that regulate carbon processing in small, headwater streams in the Chesapeake Bay watershed

Basic Information

Title:	Assessing the role of road salt run-off on the critical ecological interactions that regulate carbon processing in small, headwater streams in the Chesapeake Bay watershed
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Principal Investigators:	Christopher Swan

Publication

Assessing the role of road salt run-off on the critical ecological interactions that regulate carbon processing in small, headwater streams in the Chesapeake Bay watershed.

MWRRC Project #2007MD148B

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Final Report

Published Abstracts

P. Bogush, S.S. Kaushal & C.M. Swan. The interaction of road salt de-icer and dissolved organic carbon on microbial respiration in stream sediments. Ecological Society of America, San Jose, California, 2007

Student Support

Two graduate students (Peter Bogush, Carrie dePalma; both MS students enrolled in the Marine, Estuarine, and Environmental Science program) were supported in summer 2007 to work on the field project and to carry out the laboratory study summarized below. That study will comprise a significant portion of Peter Bogush's Master's thesis. I have another graduate student, Robin Van Meter (Ph.D., also enrolled in MEES) working on an associated project looking at the effects of road-salt contamination in ponds and associated effects on food webs. Robin aided with the project tasks. Rebecca Reeves, and undergraduate enrolled at UMBC in the Department of Geography & Environmental Systems, was supported by an NSF REU to the Baltimore Ecosystem Study LTER and also worked on the project.

Statement of Water Quality Problem

The ecological condition of streams and rivers reflect the myriad of disturbances humans make in a watershed. Elevated nutrient inputs via agricultural practices, drastically exaggerated flow regimes due to increases in impervious surface cover, and the resulting disruption of the balance between sedimentation and erosional forces typify the degraded stream ecosystem. The consequence for humans is the wholesale degradation of water quality (Herlihy et al., 1998) as habitat is modified, reducing the capacity of the biota to properly mediate natural rates of nutrient cycling (e.g., carbon mineralization, denitrification; Groffman & Mayer, 2005). Researchers have recently discovered that streams draining human-dominated landscapes can experience enhanced loading of road salt deicer (Environment Canada, 2001; Kaushal et al., 2005). Elevated levels of chloride are reported to increase with road density and impervious surface cover, reaching levels known to impair freshwater life (>250 mg l^{-1}; Hart et al., 1991; Kaushal et al., 2005). The potential for anthropogenic salinization to alter critical ecosystem processes performed by streams, specifically carbon processing, is largely unknown. Given the energetic reliance of forested stream food webs on riparian-derived, carbon-rich detritus (e.g., senesced leaf litter, wood), carbon processing in small, headwater streams is an important ecosystem function potentially at risk from elevated salt loading occurring in the region. The overall goals of this project are:

(1) to identify microbial-invertebrate ecological features critical to decomposition that are impaired by salinization,

(2) to determine the magnitude by which salinization alters decomposition rates, and

Project Objectives

While many pollutants are federally regulated, no such regulations exist for road salt. Empirical tests of the effects of road salt on stream macroinvertebrates do exist (e.g., Blasius & Merritt, 2002), and even studies of leaf decomposition in streams receiving road salt have been done (e.g., Niyogi et al., 2001), but no work to date has explicitly manipulated road salt runoff and ascertained the consequences for various ecosystem processes *in situ*. While performing studies in streams receiving various levels of salt is a valuable endeavor, there can be many co-varying factors (e.g., land use practice, nutrient inputs) that can also lead to degradation of carbon processing. Therefore, large-scale manipulations under natural conditions are needed to provide natural resource managers and decision-makers with solid information on the role salt plays in streams. The specific tasks to be undertaken are:

Task I. Manipulate salt at the reach-scale in a small, forested stream to learn how whole-reach metabolism and local community structure will react to salt stress,

Task II. Perform reciprocal transplants of leaf litter between the salt addition reach and the un-manipulated upstream control reach to learn how microbial colonization under the salt-regime changes decay in the impacted vs. un- impacted shredder communities, and

Task III. Perform feeding studies in the lab with the dominant shredder taxa found under each salt condition on salt vs. non-salt conditioned litter to determine potential changes in shredder feeding efficiencies.

Project Results

Rationale

Due to a severe drought during summer 2007 and 2008, I was unable to complete the extensive field component of the study proposed. After multiple attempts at the field work, I opted to design and carry out a complementary laboratory study to address, the tasks proposed. Following is a summary of those studies.

Small recirculating streams were maintained indoors and the interactive effect of salt loading and invertebrate feeding activity on carbon mineralization estimated. Specifically, I asked (1) does salt loading alter microbial mineralization of carbon on leaf litter, and (2) does invertebrate feeding activity alter the magnitude of the salt effect on C mineralization rates?

Methods

Recirculating stream mesocosms were created using round 26.6 l containers . Mesocosms were designed to maintain a water level of 10 cm over 1.5 cm of natural stream sediments collected from a local headwater stream (Patapsco State Park). A small submersible pump returned water from the internal center container to the outer channel, creating a flow-through environment designed to mimic the stream at baseflow. Flow in the mesocosms averaged 8.6 cm s^{-1}.

Sensenced leaf litter from American Beech was placed in litter bags (7 x 11 mm mesh) into a first-order, spring fed stream on August 13, 2008 and allowed to incubate and colonize with bacteria and fungi for 10 d. Litter was returned to the lab and ~2g wet mass of litter added to 10 separate mesocosms. All ten mesocosms received 30 individual *Gammarus* sp. (Amphipoda) and a single *Tipula* sp. (Diptera) as the shredders. These taxa are common to the streams studied at Patapsco State Park. Salt concentrations in five randomly chosen mesocosms was raised to 5 g Cl l^{-1}. To isolate the effect of shredder feeding activity on microbial degradative ability, six 2.5 cm leaf discs were placed in 300 mm mesh cages inside each mesocosm, inhibiting access by the shredding invertebrates. The invertebrates were allowed to feed for 7 d prior to the salt addition.

After 24 h of salt exposure, microbial respiration on the leaf surfaces was measured using a standard dark bottle incubation. Water from each mesocosm was placed into two 55 ml centrifuge tubes, six leaf discs from each shredder treatment (inside and outside the cages) placed separately in each tube. Dissolved oxygen was measured in each tube, then allowed to incubate in the dark at ambient temperatures under gentle agitation for ~24 h. Dissolved oxygen was then taken, leaf litter removed, dried to a constant mass at 70 ^{o}C, then combusted for 45 min at 550 ^{o}C to determined ash-free dry mass (Benfield, 2006). Oxygen uptake rates (mg O_2 h^{-1} g^{-1} AFDM) was then calculated for each salt x shredder combination.

Data was analyzed using a nested ANOVA, with shredder treatment nested within salt treatment, and post-hoc comparisons made between treatments. Significance was determined for pairwise comparisons after adjusting p-values using the Tukey HSD method. Analyses were carried out in SAS (version 9.2). Assumptions of normality of residuals were met (Shapiro-Wilkes test), however I did observe unequal variances between the shredder treatments. To address this, I grouped the residual variances by treatment using the GROUP option in PROC MIXED using the method of Littell et al., 1996.

Results & Discussion

This study revealed that in the short term (24 h), as may be typical of a natural discharge event, salt loading interacts strongly with shredder presence to alter rates of carbon mineralization on leaf litter. Salt significantly depressed microbial respiration rates by more than 38% (242.8 vs. 149.8 mg O_2 h^{-1} g^{-1} AFDM, P<0.0001) within 24 hours of the addition regardless of shredder treatment. However, there was a significant amelioration of this effect when invertebrates had access to the leaf litter (Table 1; Fig. 1). In the absence of salt, shredders had no effect on oxygen uptake rates (Fig. 1.), but in the presence of salt, shredder access to leaf litter reduced the negative impact of salt by 41.9 mg O_2 h^{-1} g^{-1} AFDM (P<0.01).

These results suggest that in the short term, salt heavy salt loading (e.g., 5 g Cl l^{-1} in this study) has the potentially to strongly reduce rates of carbon mineralization. However, if invertebrate detritivores can endure such pulses, then their presence seems to reduce the magnitude of the salt disturbance. Recent work suggests that many invertebrate taxa in Maryland streams can endure elevated chloride levels (Morgan et al 2007). Therefore, maintaining habitat conditions such that shredder taxa can survive might be an important consideration when managing the predicted negative impacts of salt loading to streams in the mid-Atlantic region.

Table 1. Nested ANOVA results. “Salt” indicates the salt treatment (+,-), and “Shredder(Salt)” is the shredder treatment (+,-) nested within salt treatment.

SOV	DF	F	P
Salt	1,16	37.7	<0.001
Shredder (Salt)	2,16	4.6	0.0260

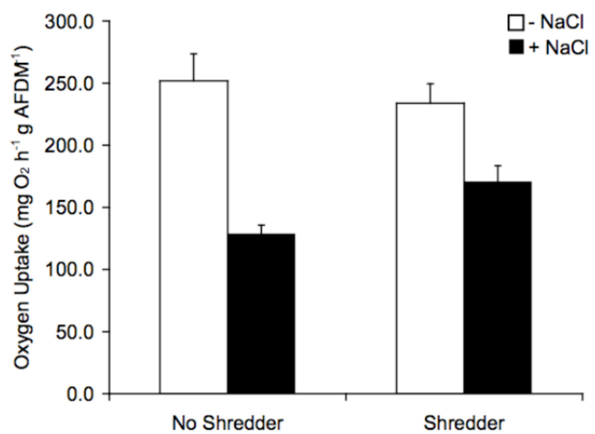

Figure 1. Results from laboratory manipulation of the presence/absence of salt stress at levels reported in freshwater in the Chesapeake Bay region (5 g Cl^- l^{-1}; Kaushal et al., 2005), and the presence/absence of invertebrate consumers (shredders) on microbial carbon mineralization (i.e., oxygen uptake) on leaf litter. These results were after 24 h of salt exposure. The presence of road salt resulted in ~50% reduction in carbon mineralization rate, but the effect was ameliorated by the presence of invertebrate consumers. Bars are means + 1 standard error, n=5 per treatment combination.

Conclusions

No federal regulations currently exist for road salt, emphasizing the importance of the observation that chloride concentrations are rising in receiving streams and rivers as impervious surface cover on the landscape increases (Kaushal et al., 2005). This, in conjunction with the predicted disproportionate increase in population growth in the mid-Atlantic region (US Census Bureau, 2005), underscores the need to understand the water quality implications of salt loading to streams and rivers. Small, headwater streams are energetically supported by organic matter inputs as leaf litter from streamside forests, and decay of the material is a complex interaction between invertebrate consumers, microbial communities and litter quality (e.g., nutrient content; Fisher & Likens, 1973; Webster & Benfield, 1986; Wallace et al., 1997; Hall et al., 2001). Mineralization of this organic matter is an important ecosystem process since it describes the rate at which nutrient input (carbon) is removed and past either up the food web to higher trophic levels or respired (Wallace et al., 1997). I show here that the microbial community responsible for carbon mineralization is negatively impacted by salt at levels currently occurring in the environment (Fig. 1). I interpret these results (Fig. 1) to suggest that road salt stress, which is predicted to continue to increase as impervious surface cover increases on the landscape, disrupts the capability of stream food webs to mediate organic matter dynamics. Interestingly, the presence of invertebrate consumers, which are known to suffer substantially from other sources of anthropogenic disturbance, including very high levels of salt (e.g., higher than we manipulated), seem to ameliorate this negative effect.

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Integration of Stormwater Management Ponds into Urban Communities: Long-term Water Quality Protection, Wildlife, and Environmental Awareness

Basic Information

Title:	Integration of Stormwater Management Ponds into Urban Communities: Long-term Water Quality Protection, Wildlife, and Environmental Awareness
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Congressional District:	3
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Focus Category:	Water Quality, Hydrogeochemistry, Ecology
Descriptors:	
Principal Investigators:	Joel Wade Snodgrass, Ryan E. Casey, Edward R Landa, Steven Lev

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Report of Activities Under Subaward Agreement Z592801: Integration of Stormwater Management Ponds into Urban Communities

PIs: Joel W. Snodgrass, Steve M. Lev, Ryan E. Casey and Ed R. Landa

Stormwater management ponds are common features of more recent development and are required by most state and local governments as part of more comprehensive stormwater management practices. While stormwater ponds are human created habitats, they may superficially resemble natural wetlands and attract wildlife. Moreover, while short-term (individual storm event) studies indicate storm water ponds are affective at removing pollutants, the effectiveness of ponds over longer time scales (years) and the interaction of these ponds with human populations have received little or no attention. Our work seeks to evaluate pollutant movement between ponds and streams through groundwater transport, the role of ponds as wildlife habitat for amphibians, and social perception and understanding of ponds. Below we outline our progress under four specific goals.

Goal 2: Determine to what degree metals (primarily Cr, Cu, Ni, Pb, and Zn) and Cl^- are transported via ground water from ponds where they accumulate to natural surface waters

To quantify contaminant loading to stormwater ponds and flux to surface waters in the Red Run watershed via groundwater transport, we set up a dense monitoring network at two ponds. We installed 50 drive point piezometers within the ponds and on the floodplain between the ponds and a second-order tributary to Red Run. We place water level and conductivity loggers at inputs to the ponds and up and down stream of the floodplain input within the second-order tributary. We measured stream discharge and collected water samples from the wells and stream on a regular basis.

At the study site, discharge in the second order tributary downstream of input from the stormwater ponds is generally 2.5 times higher and chloride levels are 5 times higher than an upstream reference site. Surface water measurements immediately downstream of storm water derived input record elevated conductivities year round in the stream, peaking at approximately 2.5 mS/cm. A chloride enriched groundwater plume moving down gradient from the retention ponds has also been identified. Groundwater conductivities remain elevated throughout the year peaking at > 20 mS/cm in ground water immediately under the ponds in late winter. Under the floodplain ground water conductivties also remain elevated year round with a high of 5.85 mS/cm occurring during the winter months. These finding clearly indicate that road salts entering retention ponds are being transferred to ground waters where they are stored and, ultimately discharged to streams.

Soil porosity and hydraulic conductivities are currently being estimated for the floodplain in order estimate chloride storage and flux. Water samples are also being analyzed for trace metal levels.

Goal 2: Determine if there are interactions between the types of pollutants that accumulate in stormwater ponds that might facilitate or otherwise influence ground water transport of pollutants.

To assess the effects of road salt contamination of soils on bioavailability of Zn we conducted a series of experiments with a common earth worm, *Lumbricus terrestris*. In the first experiment *L. terrestris* was exposed to OECD artificial soil amended with Zn and NaCl or $CaCl_2$. After salt application OECD soil exhibited the intended treatment effect, with Na^+ and Ca^{2+} accounting for 74 and 96% of soil cation exchange sites, respectively. Deionized water phase Zn also varied between treatments, averaging 3.4 times higher in the Ca^{2+} treatment. Despite this difference in available Zn, earthworms did not accumulate Zn or other trace metals in either treatment over the course of a 22-day exposure. We observed complete mortality in the Na^+ treatments at day 22 (8 worms), and consequently considered that a relationship between the biologically relevant ions Na^+ and K^+ may have caused stress.

In our second experiment we chose to further explore the importance of Na^+:K^+ in earthworms by treating a field derived soil with a suite of five concentrations, which allowed us to achieve Na^+:K^+ ratios in the soil ranging from 3.5 to 190; values both greater and less than those observed in local stormwater pond soils. Increasing amounts of Na^+ in the soil led to marked changes in soil cation composition, with all major cations except Na^+ showing decreases over time. Earthworm biology was also affected, with average percent weight losses of 5.7, 12, 17, 17 and 43 for the five treatments. While $Na^+:K^+$ ratio did seem to be significantly higher in salt treated soil than the control, we did not observe a dose-dependent effect. Our results suggest that the road salts may be affecting soil communities by limiting the availability of major cations.

Goal 3: Determine the range of pollutants and hydrological conditions exhibited by typical ponds and the degree to which they degrade habitat for developing embryonic and larval amphibians.

To address the potential for pollutant exposure for wildlife, we randomly selected 68 stormwater ponds in the Red Run watershed of Baltimore County, Maryland. We sampled sediment and water in the 68 ponds to estimated the proportion of ponds in a third-order watershed that exceed toxicity guidelines for trace metals and polycyclic aromatic hydrocarbons in sediments and chloride in surface waters. Ninety-six percent of ponds exceeded consensus-based threshold effect concentrations for at least one trace metal. Nine percent of ponds exceeded chronic toxicity levels of chloride on all sampling dates, and 21% exceeded acute toxicity concentrations on at least one sampling date.

We also surveyed hydrology and Wood Frog (*Rana sylvatica*) use of the 68 randomly selected ponds. Wood Frog use of ponds was associated with both hydrology and Cl^- water levels. Wood Frogs only bred in ponds with relatively long hydroperiods (drying only in mid to late summer) and Cl^- levels less than ~250 mg/L. A set of laboratory bioassays involving exposure of embryos and larval Wood Frogs to sediments from six ponds confirmed that road salt contamination was at least partially responsible for limiting Wood Frog use of ponds. Pond treatments with water chloride concentrations above approximately 260 mg/L saw reduced or no larval survival.

Goal 4: Examine breeding habitat choice in natural and recently urbanized landscapes to determine if amphibians select or avoid stormwater ponds as breeding sites.

To investigate the potential impacts of stormwater ponds on amphibian populations we intensively surveyed three second-order watersheds of the larger Red Run watershed and three second-order watersheds that were predominately forested (Brand and Snodgrass, *in press*). In suburban watersheds, most (89%) of the wetlands that had breeding activity were either stormwater ponds or were otherwise artificial. This pattern was also evident in the forested watersheds, where amphibians were primarily found breeding in wetlands created by past human activity. Late-stage larvae were found only in anthropogenic wetlands in all study areas because the remaining natural wetlands did not hold water long enough for larvae to complete development. Our results suggest that in urban and suburban landscapes with naturally low densities of wetlands, wetlands created by current or historic land uses may be as important to amphibian conservation as natural wetlands or pools.

Literature cited

Brand, A. B., and J. W. Snodgrass. In press. Value of Artificial Habitats for Amphibian Reproduction in Altered Landscapes. *Conservation Biology*.

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3. Yang, N., Wang, S.L. and Schonfeld, P. "Simulation-Based Optimization of Waterway Projects using a Parallel Genetic Algorithm," Annual Transportation Research Board Meeting, January 2008, (08-2571).

Status Report on Detailed Lock Model
Phase 2

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Introduction

In continuing the work from Phase I of this project, the DLM development focuses on the following tasks in the Phase II:

- integrating DLM and NaSS,
- preparing detail lockage time outputs,
- setting up lockage rules for specific vessel type
- scheduling maintenance closure,
- modeling various control policies.

Since DLM will be one of the modules in NaSS, the integration at the early development stage is important. With complete integration, DLM is able to successfully receive the relevant information sent from Basin model, perform the specific functions developed in DLM, and deliver the useful outputs. The detailed integration steps are documented separately in another report. This report then briefly summarizes the progress in phase II development.

1. Detailed Lockage Time

The four-stage lockage process modeled in DLM includes the approach, entry, chambering and exit components. The start and end times for each of these lockage components is recorded in DLM. After receiving those recorded times, NaSS is able to perform the animation (if necessary) based on those component timings during the simulation.

2. Lockage Rules for Specific Vessel Type

Vessel class is defined uniquely in NaSS. Vessel type is then defined based on the common features in vessel class. That is, one vessel type can cover more than one vessel class. Currently there are five vessel types are defined in DLM (as shown in Table 1). Lockage rules are applied based on the vessel type.

1. **T** represents commercial tows
2. **L** represents light boat
3. **H** represents high priority vessels which include government vessels and passenger vessels
4. **R** represents recreational vessels
5. **O** represents other vessels.

Table 1 Definitions of Vessel Class and Vessel Type

tblVesselClass : Table

	VesselClassID	VesselClass	VesselType
▶	1	TowSmall	T
	2	TowLarge	T
	3	Barge	
	4	Chem Barges	
	5	Coal Barges	
	6	Empty Barges	
	7	EquipMach Barges	
	8	FoodFarm Barges	
	9	ManufGoods Barges	
	10	MiscUnknown Barges	
	11	Petro Barges	
	12	CrudeMat Barges	
	13	Tow	T
	14	Light Boat	L
	15	Recreation Vessel A	R
	16	Recreation Vessel B	R
	17	Recreation Vessel C	R
	18	Government Vessel	H
	19	Passenger Vessel	H
	20	Other Vessel	O
*	0		

2.1 Passenger and Government Vessels

Passenger and government vessels are generally considered high priority vessels and are sent to the head of the queue as soon as they arrive. If there are multiple high priority vessels in the queues, they are served with the FIFO policy.

2.2 Tows, Light boats and other Vessels

Tows, light boats and other vessels should be treated similarly. They are processed as commercial lockages. These vessels are likely to be included in a multi-vessel lockage, depending on their sizes.

2.3 Recreation Vessels

Recreational vessels are generally treated with rules applicable only to recreation craft. There are specific recreational policies which might be varied at different lock locations. Two tables (Table 2 and Table 3) are established to present the various recreational policies.

Table 2 Policies for Recreational Vessels

tblRecPolicy : Table

	RecPolicyID	LockID	ChamberID	WaitLockage	AllowedInTB	NumOfPeriods
▶	1	54	83	0	☑	0
	2	54	84	3	☑	3
*	0	0	0	0	☐	0

Table 3 Time Window for Serving Recreational Vessels

tblRecPolicyTimeWindow : Table

	RecPolicyTimeID	ChamberID	RecPolicyID	Period	Exclusive	StartTime	EndTime
▶	1	84	2	1	☑	9	10
	2	84	2	2	☑	15	16
	3	84	2	3	☑	18	19
*	0	0	0	0	☐	0	0

(1) Policy 1: maximum wait commercial lockage

If this policy is in effect, recreational vessels can be made to wait n (e.g. n=3) commercial lockage. Recreational vessels which have waited for n or more commercial lockages have higher priority to be served by chambers than commercial tows.

(2) Policy 2: recreation lockage schedules

If this policy is in effect, a chamber will serve the recreational craft during pre-specified time periods.

If the policy is nonexclusive, at the special time periods the chamber serves not only recreation vessels but also other types of vessels.

If the policy is exclusive, only recreation vessels can be served at the special time periods at a chamber.

3. Scheduled Major Maintenance Closures

Scheduled Closures on a Recurring Cycle

The user can set a scheduled outage as either a one-time or an annual recurring event, with a start date and duration. When the chamber is closed on schedule, the chamber will be set out of service after it finishes serving the vessels that have already started to be served. Those vessels that have been assigned to this chamber but are waiting at the approach point because of interference or other reasons will be released to the lock queues so that they can be re-assigned to other open chambers. When the chamber is back of service after repair, it will look for the next vessel in the lock queue to start its service again. In the current Phase 2, we consider chamber-level outage instead of component-level outage.

4. Lockage Policies

As chamber specific characteristics, two types of control policies are considered in DLM (as shown in Table 4). One is the static control policy which is fixed over time. The other is the dynamic control policy whereby control policies are adaptive to change based on congestion level (e.g., queue length, waiting time…) at the lock as the simulation progresses.

Table 4 Chamber Characteristics

tblChamber : Table

	ChamberID	LockID	ChamberDesc	Main	Length	Width	CutLimit	ControlPolicyID	DynamicControl
▶	83	54	Marmet	☑	360	56	5	1	☑
	84	54	Marmet	☐	360	56	1	6	☐
*	0	0		☐	0	0	0	0	☐

Table 5 lists the defined static control polices. Policies with different parameters, though with the same policy name, are labeled with different control policy ID. For instance, there are listed three N-up M-down policies with their own UpCount and DownCount parameters.

Table 5 Static Control Policies

tblLockPolicy : Table

	LockPolicyID	LockPolicyDescription	LockPolicy	Direction	UpCount	DownCount	FairnessValue
▶	1	FIFO	FIFO	0	0	0	0
	2	N-Up M-Down	NupMdown	0	3	3	0
	3	N-Up M-Down	NupMdown	0	6	6	0
	4	N-Up M-Down	NupMdown	0	12	12	0
	5	One Way	OneWay	1	0	0	0
	6	One Way	OneWay	2	0	0	0
	7	Longest Queue	LongestQueue	0	0	0	0
	8	Shortest Processing Time First	SPF	0	0	0	0
	9	Fairer Shortest Processing Time First	FSPF	0	0	0	5
	10	Fairer Shortest Processing Time First	FSPF	0	0	0	7
*	0			0	0	0	0

Table 6 and Table 7 defined the dynamic control policy which includes a group of static control policies. The thresholds triggering policy switch are user defined. For example, during low congestion, short queue lengths, the policy will probably be FIFO. Then as congestion and the tows in queue rise to say 6 in one direction, the policy will switch to 3-up 3-down. If congestion rises further, it may change to 6-up 6-down. Then as congestion decreases, the control policy may switch back to FIFO. The queue lengths that trigger such changes in control policy will be data inputs.

Table 6 Dynamic Control Policies

tblLockPolicyDynamics : Table

	LockPolicyDynamicsID	DynamicPolicyGroupID	LockPolicyID	ThresholdType	QueueTH	TimeTH
▶	1	1	1	Q	0	0
	2	1	2	Q	4	0
	3	1	3	Q	7	0
	4	1	4	Q	13	0
	5	2	1	Q	0	0
	6	2	2	Q	5	0
	7	2	3	Q	8	0
	8	3	5	Q	1	0
	10	4	6	Q	1	0
	12	5	1	T	0	0
	13	5	8	T	0	100
	14	6	1	T	0	0
	15	6	8	T	0	100
	16	6	9	Q	7	0
*	0	0	0		0	0

Table 7 Definition of Policy Group for Dynamic Control Policies

tblLockPolicyGroup : Table

DynamicPolicyGroupID	PolicyGroup	GroupDescripttion
1	NupMdown	FIFO / 3-level N-up M-down
2	NupMdown	FIFO / 2-level N-up M-down
3	OneWay	One Way (Mutually)
4	OneWay	One Way (Mutually)
5	SPF	FIFO / SPF
6	FSPF	FIFO / SPF / FSPF
(AutoNumber)		

Four control policies, with their static or dynamic features, are modeled in current phase. Those control policies are only applied in tows / other vessels, not recreational or high priority vessels. Each control policy has its own assumptions and specific operation rules. More details are provided below.

4.1. Static Control Policies

4.1.1 FIFO

First in, first out (FIFO) is a most common service policy in inland waterway network. FIFO is viewed as the fairest control policy which locks vessels based on their arrival order, without any service preference. Whenever an available chamber looks for next serving vessel, the earliest arriving one is always chosen.

4.1.2 N-Up M-Down

N-Up M-Down represents the serving sequence of the waiting queues. All iterations should be completed by serving N and M vessels from upbound and downbound directions, respectively. If the starting direction is downbound, the system will try to look for M vessels, one by one, from downbound queue with earliest arrival time that satisfies cut limits as the next vessel. It should noted that N-up M-down is not multi-vessel lockage. N or M vessels are served individually, multiple chamber turnback times.

There are a few assumptions made about the N-Up M-Down control policy:

(1) Once we decide to use the N-Up M-Down control policy, the starting direction (i.e. up or down) is initialized by the first arriving vessel when the chamber is idle.

(2) The N-Up M-Down policy only applies to tows and other vessels. Passenger / government vessels and certain specific recreational crafts still have the priority to use the available chamber.

(3) For 3-Up 3-down, it is ok to lock vessels with 3-Up 1-down, 3-Up 2-down, 1-Up 3-Down, or 2-Up 3 down since one direction might not have that long queue compared with other direction. The policy automatically ends when the queue in any direction has dissipated.

The basic logic of N-up M-down is shown in Figure 1.

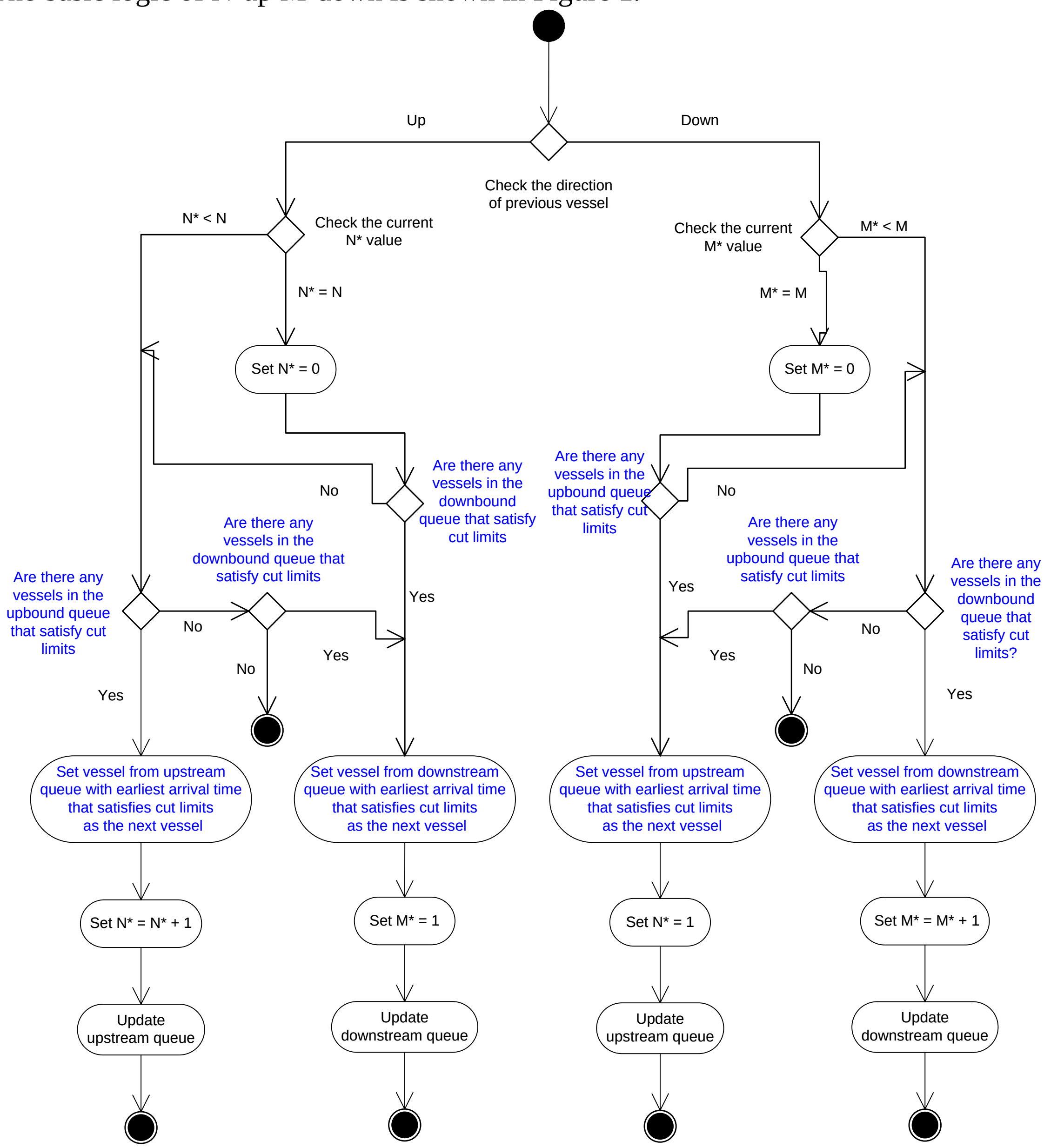

Figure 1 Operational Logic of N-up M-down

4.1.3 One-way

One way policy indicates that upbound and downbound traffic are served by two chambers respectively. Each chamber is uniquely assigned to one direction. Thus, a single chamber lock will not have a one-way policy.

The control policy for one-way operation is similar to 'one direction FIFO'. The overall logic is also similar to FIFO while dealing with traffic from one direction. This preferred direction is pre-determined among chambers. There could be a fixed one-way policy or preferred one-way policy. That is, if there is no vessel waiting in the preferred direction or the queue is very unbalanced by direction, the available chamber can temporarily switch to serve the opposite direction, until the next upcoming vessel from the preferred direction. The Figure 2 shows the logic for one-way policy.

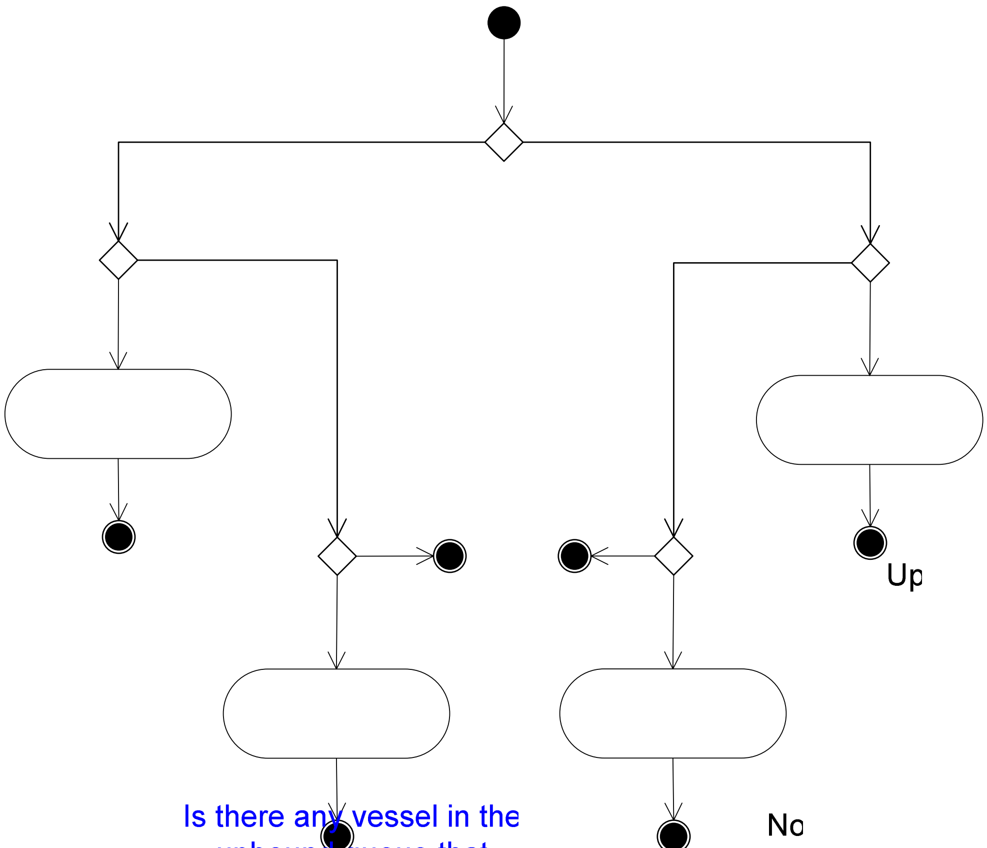

Figure 2 Operational Logic of One-Way

4.1.4 Longest Queue

With the longest queue policy, the next vessel is selected from the direction with the longest waiting queue. Similarly, the overall logic is the same as the FIFO, but only based on the longest queue.

At beginning, the lockage operator should check the lengths of all queues. Once the longest queue direction has been determined, the earliest vessel waiting in this queue that satisfies the cut limits constraint is assigned to the available chamber. If none of the vessels in the longest queue satisfy the cut limit restriction, the available chamber will look for the next vessel from the opposite direction. If the queue lengths in both directions are identical, the chamber will look for the earliest vessel satisfying the cut limit constraint. The basic logic of longest queue policy is shown in the Figure 3.

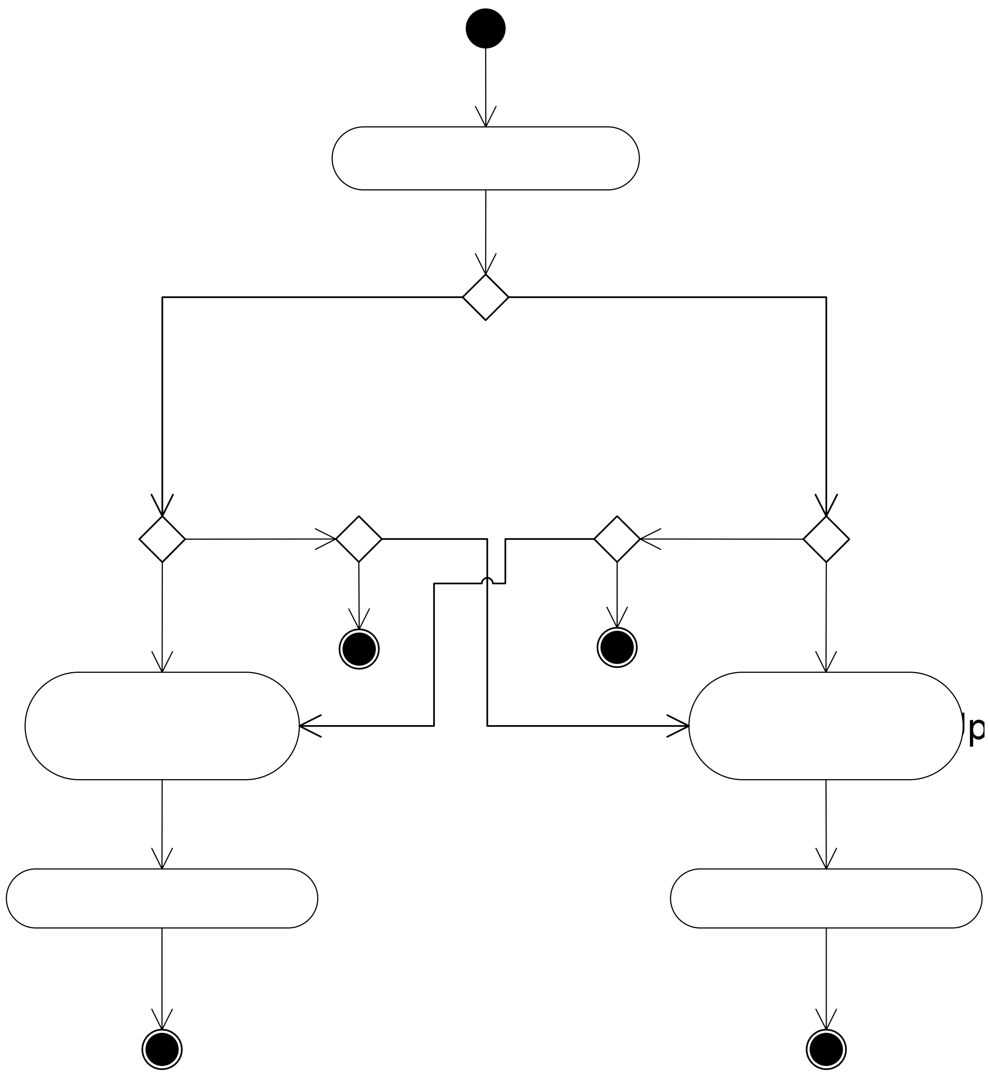

Figure 3 Operational Logic of Longest Queue

4.2. Dynamic Control Policies

4.2.1 Definition

In control problems of queuing systems, the "switch"-form dynamic control policies usually be considered as a more effective stategy. A dynamic control policy can automatically switch between regular static queue disciplines when one or several levels of service (LOS) reach pre-determined thresholds. The selection of a proper level of service and determination of the value of thresholds are also optimization problems which need further studies. Thus the LOS and the thresholds should be input items in current phase.

The current DLM supports dynamic control policies which can switch policies in real-time according to the current total queue length or the current time period.

4.2.2 Thresholds

As shown in the Figure 4, a dynamic control policy consists of several static control policies (Policy *i*). The control kernel selects the corresponding static policy based on the evaluation of the current LOS (level of service) and pre-determined thresholds (T_i).

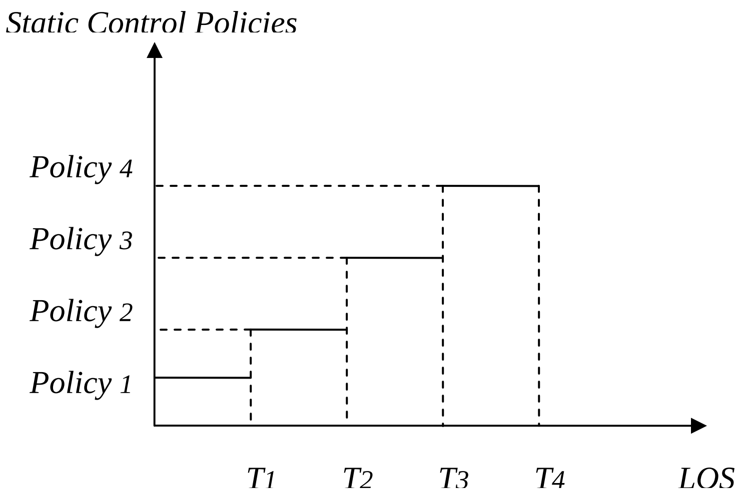

Figure 4 Logic for Switching Control Policies

4.2.3 Example

Figure 5 demonstrates an example of dynamic N-up M-down control policy, where

(1) T_1 is the threshold value between FIFO and "3-up 3-down," T_2 is the threshold value between "3-up 3-down" and "6-up 6-down," and T_3 is the threshold value between "6-up 6-down" and "12-up 12-down."

(2) Among FIFO, "3-up 3-down," "6-up 6-down," and "12-up 12-down" can change to others through a 'reevaluation' procedure which measures the current LOS.

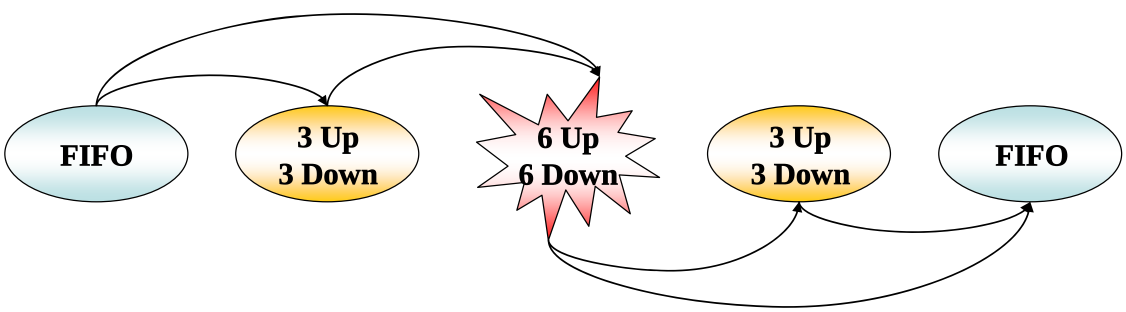

Figure 5 Dynamic Policy Evaluation

Status Report on Detailed Lock Model
Phase 3

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Introduction

In continuing the work from Phases 1 and 2 of this project, the DLM development focuses on the following tasks in the Phase 3.

- **Modeling additional control policies**

  In Phase 2, four control policies have been modeled, namely FCFS (First Come First Serve), N-Up M-Down, One Way and Longest Queue. Two more control policies, SPF (Shortest Processing Time First) and FSPF (Fairer SPF), are included in the DLM. 14 other control policies are left for future development.
- **Enhancing the efficiency of multi-cut lockages**

  For multi-cut tows, towboats sometimes must be locked back and forth to complete multi-cut lockages. Therefore, if helper boats are available at locks, it could help speed up the lockage service and enhance the locking efficiency.
- **Modeling multi-vessel lockages**

  At some locks, multiple smaller-size commercial vessels can be served together during one lockage. This saves time on multiple lockages.
- **Considering mixed vessel lockages**

  Unlike multi-vessel lockages, mixed-vessel lockages, process commercial and non-commericial vessels together.
- **Locking recreational vessels in groups**

  Since most of recreational vessels are small compared with commercial vessels, recreational vessels are usually locked as a group, which might contain up to 50 vessels according to LPMS data.
- **Modeling interference for multi-chamber locks**

  Issues of physical interference between vessels are always considered at multi-chamber locks. Such lock interference sometimes forces the waiting vessel to wait longer even when there are available chambers ready for service. Such interference can also block vessels from exiting even after their chambering is completed.
- **Including scheduled outage**

  Much maintenance work results in scheduled outages. These could be one-time or recurring events. During outages, chambers are closed for service and vessels are wait in queues without any re-routing consideration in current DLM development.
- **Considering open pass and navigation pass**

  Navigable pass and open pass occur at some locks when water levels are high enough to let vessels pass through without a chambering process.

In this phase, a detailed shipment list (DSL) for single lock is included for the first time. With historical shipment data, all the O/D information, vessel type information, vessel size information, commodity information and information on lockage time distributions are provided in detail. Model validation can be based on such real-world information. In addition, some detailed vessel definitions have been modified in this phase, compared with the previous two phases, to model the complex lockage rules in DLM with clearer categorization.

Vessel Definitions

Since various lockage rules may be applied to different vessels in the DLM, vessel characteristics are clearly defined in three tables: vessel class, vessel type and vessel policy group. Figure 1 shows the relations among those three tables.

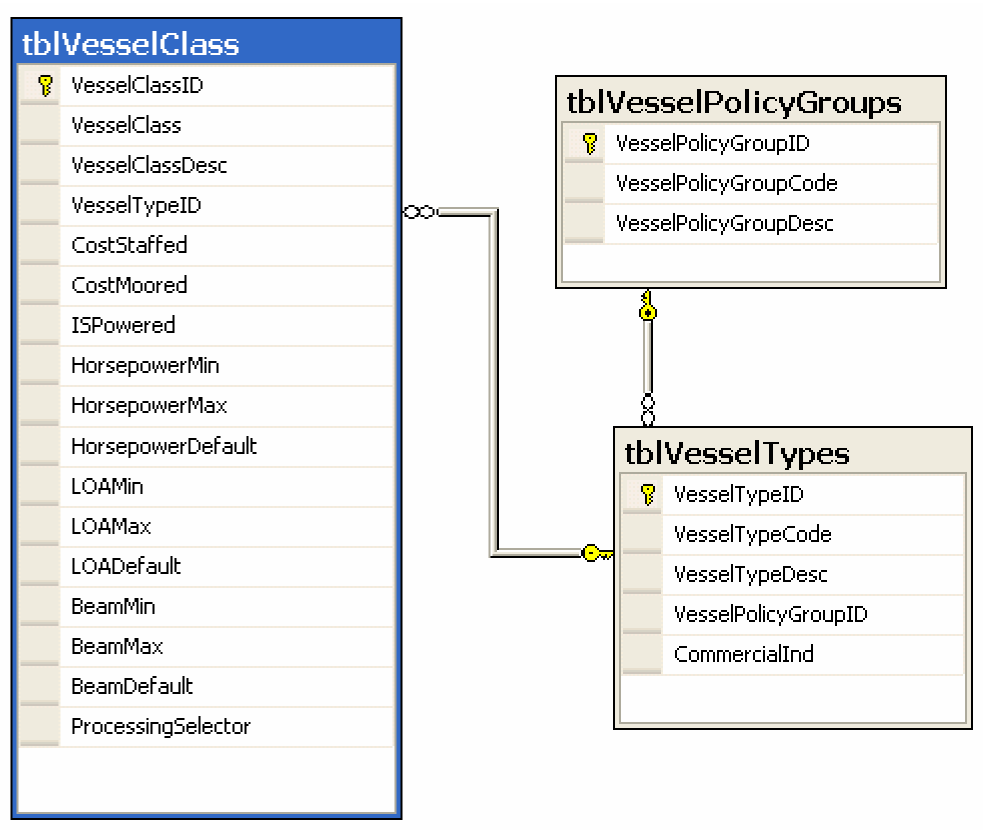


Figure 1 Relationship between Vessel Definitions

Vessel Class

The detailed features for the vessel with type, dimensions, horse power, etc., are defined in the vessel class table. With their dimensional information, currently there are 444 different vessel classes which could be unpowered vessels, such as various barges, and powered vessels, such as tow boats or recreational craft. Table 1 shows part of the vessel class table. Those vessel classes are further grouped with different vessel types, as seen in the “VesselTypeID” column.

Table 1 Vessel Class

	VesselClass	VesselClassDesc	VesselTypeID	CostStaffed	CostMoored	ISPowered
▶	T1	Towboat up to 1...	11	0	-1	True
	T2	Towboat 1201-1...	11	0	-1	True
	T3	Towboat 1401-1...	11	0	-1	True
	T4	Towboat 1801-2...	11	0	-1	True
	T5	Towboat 2301-3...	11	0	-1	True
	T6	Towboat 3401-5...	11	0	-1	True
	T7	Towboat 5001-5...	11	0	-1	True
	T8	Towboat 5601-8...	11	0	-1	True
	C	Dry Cargo Vessel	1	0	0	True
	E	Liquid Cargo Vessel	2	0	0	True
	F	Fishing VesselFla...	3	0	0	True
	G	Federal Govern...	4	0	0	True
	J	Dredge Vessel	5	0	0	True
	K	Crewboat Vessel	6	0	0	True
	M	Non-Cargo Vessel	7	0	0	True
	N	Government-No...	8	0	0	True
	P	Passenger Boat ...	9	0	0	True
	R	Recreational Ves...	10	0	0	True
	U	Federal Govern...	12	0	0	True
	Z	Other Vessel	13	0	0	True
	AAB	60 ft Long, 27 ft...	14	0	0	False
	AAC	60 ft Long, 27 ft...	14	0	0	False
	AAF	60 ft Long, 27 ft...	14	0	0	False

Vessel Group Policy

Three policy groups are defined in DLM. For most commercial vessels (as shown in Table 2), a standard lockage process is applied with no priority and no specific rule. Control policies, other than FCFS (first come first serve), might be applied to this group of vessels. Those various control policies are used to select a vessel from the queue. Most government vessels and passenger vessels have the highest priority for lockage And can pass other vessels which arrived ahead of them. For recreation vessels there are various lockage restrictions. They might be prohibited in some chambers or overpassed by commercial vessels.

Table 2 Vessel Policy Group

	VesselPolicyGroupID	VesselPolicyGroupCode	VesselPolicyGroupDesc
▶	1	B	BargeClass
	2	S	Standard Processing
	3	R	Recreation
	4	H	High Priority
*	NULL	NULL	NULL

In order to correctly process the lockage upon different vessel policies, there are three queues, for each direction, will be created in DLM based on their various policies: queue for tows, queue for high priority vessels, and queue for recreational vessels.

Vessel Type

Different vessel types are defined with their commercial characteristics and applied lockage rules. In Table 3, there are 15 vessel types with various commercial vessels, different government vessels, passenger vessels and recreational vessels. The "VesselPolicyGroupID" column is used to indicate the lockage rule applied to a specific type of vessel. The "CommercialInd" column indicates a vessel's commercial characteristic. This indicator is used to determine if a specific type of vessel can participate in a multi-vessel lockage.

Table 3 Vessel Type

	VesselTypeID	VesselTypeCode	VesselTypeDesc	VesselPolicyGroupID	CommercialInd
▶	1	C	Dry Cargo Vessel	2	True
	2	E	Liquid Cargo Vessel	2	True
	3	F	Fishing Vessel	2	True
	4	G	Federal Govt. Vessel	4	False
	5	J	Dredge Vessel	2	True
	6	K	Crewboat Vessel	2	True
	7	M	Non-Cargo Vessel	2	True
	8	N	Government-NonFederal	4	False
	9	P	Passenger Boat or Ferry	4	True
	10	R	Recreational Vessel	3	False
	11	T	Tow with Barges	2	True
	12	U	Federal Govt. Contractor Vessel	4	True
	13	Z	Other	2	True
	14	B	Barge	1	False
	15	L	LightBoat	2	True
*	NULL	NULL	NULL	NULL	NULL

Thus, based on the previous 2 tables (Table 1 &Table 2), DLM re-categorizes these vessel types as follows in order to apply the locking policy:

- B is an unpowered barge.
- G, N, P and U have high priority in lockage.
- R is a recreational vessel.
- A commercial tow is T. If there is no barge, the tow is L. T, C, E, F, J, K, M and Z are all counted as power vessels without barges, just like L.

DLM Shipment List

In addition to being a lock module within NaSS, DLM is also designed to be driven independently to provide detailed analysis at any single lock. When DLM is operated as an independent model, vessel traffic should be either prepared in advance as a shipment list or generated within the model based on arrival rates and distributions. For test and validation purposes, a shipment list is used for vessel inputs. However, for planning purposes, it is preferable to generate vessel traffic while running the simulation in order to take into account the future traffic changes.

As in running NaSS, the shipment list for the DLM should include trip information such as arrival times, origin/destination, vessel types, barge sizes and other details. The number of required cuts could then be determined based on the barge sizes and chamber size. Unlike the shipment list used in NaSS, there are no "other visits" (i.e. stops for loading/unloading) between origin and destination nodes for each single trip. Although loading/unloading and docking/undocking activities might not occur during the trips, vessel re-configurations or chamber packing/unpacking maneuvers could occur while locking the vessels.

Shipment Data

Currently, the detailed shipment list (DSL) for a single lock is generated by DAPP. The information for each individual trip is covered by 7 tables (as listed in Table 4).

Table 4 DLM Data for Vessel Traffic

Shipment List
tblPowerTrips
tblVisit
tblPowerTransaction
tblBargeTransaction
tblPowerVessel
tblVesselClass
tblVesselType
tblCommodity

For a single lock, the origin and destination nodes are the two ends of a lock reach. First, *tblPowerTrips* (as shown in Table 5) provide the information on a trip's date and its O/D and *tblVisit* (in Table 6) shows the visits for each single trip. In DLM, there are only two "visits" of origin and destination. At the "origin" visit, each trip starts with its power vessel shown in *tblPowerTransaction* (as shown in Table 7), as well as barges (with or without commodity), shown in *tblBargeTransaction* (as shown in Table 8). Power vessels (i.e., towboats) are always added at the origin visit only. Barges are added as sets based on the barge type (i.e., VesselClassID) and carried commodity (i.e., CommodityID). A tow trip could have several barge sets which have varied barge types and loaded commodities.

Table 5 Power Trips

	PowerTripID	TripDate	OriginNodeID	DestinationNodeID	TripTrackingFlag
▶	1	4/12/2007 9:35:00 AM	213	214	NULL
	2	4/12/2007 3:05:00 PM	214	213	NULL
	3	6/9/2007 9:50:00 AM	213	214	NULL
	4	6/9/2007 5:15:00 PM	214	213	NULL
	5	9/18/2007 9:40:00 AM	213	214	NULL
	6	9/18/2007 5:55:00 PM	214	213	NULL
	7	11/29/2007 12:15:00 PM	213	214	NULL
	8	11/30/2007 7:30:00 AM	214	213	NULL
	9	1/12/2007 2:55:00 PM	213	214	NULL
	10	4/9/2007 2:15:00 PM	213	214	NULL
	11	4/12/2007 9:00:00 AM	214	213	NULL
	12	7/2/2007 7:45:00 AM	213	214	NULL
	13	7/3/2007 12:00:00 PM	214	213	NULL
	14	7/3/2007 12:50:00 PM	213	214	NULL
	15	7/5/2007 11:05:00 AM	214	213	NULL

Table 6 Visits

	VisitID	PowerTripID	ActionNodeID	VisitOrder
▶	1	1	213	1
	2	1	214	2
	3	2	214	1
	4	2	213	2
	5	3	213	1
	6	3	214	2
	7	4	214	1
	8	4	213	2
	9	5	213	1
	10	5	214	2
	11	6	214	1
	12	6	213	2
	13	7	213	1
	14	7	214	2
	15	8	214	1
	16	8	213	2
	17	9	213	1
	18	9	214	2
	19	10	213	1
	20	10	214	2

Table 7 Power Transaction

PowerTransacti...	VisitID	PowerVesselID	AddOrRemove
1	1	0065505	True
2	3	0065505	True
3	5	0065505	True
4	7	0065505	True
5	9	0065505	True
6	11	0065505	True
7	13	0065505	True
8	15	0065505	True
9	17	0224533	True
10	19	0227875	True
11	21	0227875	True
12	23	0227875	True
13	25	0227875	True
14	27	0227875	True
15	29	0227875	True

Table 8 Barge Transaction

BargeTransacti...	VisitID	VesselClassID	AddOrRemove	Quantity	CommodityID	QtyTons
1	1	91	True	1	2	0
2	2	91	False	1	2	0
3	3	91	True	1	2	0
4	4	91	False	1	2	0
5	5	91	True	1	2	0
6	6	91	False	1	2	0
7	7	91	True	1	2	0
8	8	91	False	1	2	0
9	9	33	True	1	38	1500
10	10	33	False	1	38	1500
11	11	33	True	1	38	1500
12	12	33	False	1	38	1500
13	15	60	True	1	2	0
14	16	60	False	1	2	0
15	17	91	True	1	38	10
16	18	91	False	1	38	10
17	19	384	True	1	38	500
18	20	384	False	1	38	500

Although a tow speed is specified for each single reach, including a lock reach, currently tow speed is not applied while running DLM since a lock reach is defined between two approach points and all the lockage times are determined from various processing time distributions.

Read DLM Traffic

When driving DLM as a stand-alone model, all the shipment data are loaded at the beginning. The relevant cut information is also calculated based on the packing algorithm used by the network model, BasinSym. In addition to the arrival time and detailed barge/commodity information, DLM also needs vessel type information and dimensional information for each cut. Vessel type information is used to model the chamber preference, chamber exclusion, lockage priority, as well as various lock control policies. The dimensional information for each cut is necessary for considering interference and multi-vessel lockage.

Vessel Type

If there are barges (non-powered) with a power vessel, that is considered a commercial tow trip. If there are no barges with a power vessel, this might indicate trips of towboats, government vessels, passenger vessels, recreation vessels, etc. That information is provided in *tblPowerVessel* (as shown in Table 9), in which the vessel class is indicated for each individual power vessel. Based on the vessel class, the vessel type is then given in *tblVesselClass* (as shown in Table 10). All the vessel types and their policy groups are defined in *tblVesselType* (as shown in Table 3) as well as in *tblVesselPolicyGroup* (as shown in Table 2).

Table 9 Power Vessel

	PowerVesselID	VesselClassID	HP	LOA	Beam
▸	0000100	1	600	82	24
	0000101	1	600	82	24
	0000110	1	600	82	24
	0000205	1	600	82	24
	0000220	20	900	*NULL*	*NULL*
	0000360	1	600	82	24
	0000760	1	600	82	24
	0000776	1	600	82	24
	0000900	1	600	82	24
	0000999	1	600	82	24

Table 10 Vessel Class

VesselClassID	VesselClass	VesselClassDesc	VesselTypeID
1	T1	Towboat up to 1200 HP	11
2	T2	Towboat 1201-1400 HP	11
3	T3	Towboat 1401-1800 HP	11
4	T4	Towboat 1801-2300 HP	11
5	T5	Towboat 2301-3400 HP	11
6	T6	Towboat 3401-5000 HP	11
7	T7	Towboat 5001-5600 HP	11
8	T8	Towboat 5601-8400 HP	11
9	C	Dry Cargo Vessel	1
10	E	Liquid Cargo Vessel	2
11	F	Fishing VesselFlat or Deck Barge	3
12	G	Federal Government Vessel	4
13	J	Dredge Vessel	5
14	K	Crewboat Vessel	6
15	M	Non-Cargo Vessel	7
16	N	Government-Nonfederal Vessel	8
17	P	Passenger Boat or Ferry	9
18	R	Recreational Vessel	10
19	U	Federal Government Contractor Vessel	12
20	Z	Other Vessel	13

Cut Information

The dimensions of the chamber and tow are needed in order to determine the required number of cuts. According to BasinSym, "chamber signature" and "tow signature" are used to define this dimensional information. Chamber signature is a string used to identify chambers of equivalent dimension and assistance availability. The components for the chamber signature are length, width, and assistance. Chamber size can be read from Length and Width in *tblChamber*. If assistance is available, the power vessel is locked through with only one cut. If assistance is not available, the power vessel is required to accompany each and every cut. An example of chamber signature for a chamber which is 360 feet long and 56 feet wide with assistance would be 360×56×ASSIST.

Tow signature consists of a dimensional signature of the power vessel and 0 or more barge set signatures where the barge sets have been decomposed to barges of similar dimensions. The power vessel signature is its length and width in integer feet. It can be read from LOA and Beam in *tblPowerVessel*. The barge set signatures consists of length, width and number of barges. The length and width can be read from LOADefault and BeamDefault in *tblVesselClass* based on the VesselClassID in *tblBargeTransaction*. The quantity for each barge set is also shown in *tblBargeTransaction*. If a towboat labeled "0003314" pushes two barge sets of six 60"×27" liquid cargo barges

(VesselClassID 27) and nine 61”×31” open hopper barges (VesselClassID 29), the tow signature is expressed as [115×23](60×27×6)(61×31×9).

With the tow and chamber signature, information for each cut may be calculated. There are three types of cut information:

1. Number of cut,
2. Dimension of each cut, especially length of cut
3. Remaining chamber length after fitting in each cut, especially for single-cut tow

DLM locks different cuts through the same lockage process steps, including cut approach, entry, chambering and cut extraction. The length of each cut sitting at the gate area, either waiting for the chambering or waiting for the exit, affects the gate area interference in DLM. With the remaining chamber length left after a small vessel has fitted into the chamber, another small vessel could be locked in a single lockage cycle, thus saving the lockage time for two different lockage cycles.

Lock Control Policy

In this phase, two additional control polices are modeled. SPF (Shortest Processing Time First) has already been discussed in the simulation text book (Law and Kelton, 2000). It provides a way of re-sequencing the queue. Due to the re-sequencing, we should reconsider whether FCFS is the fairest way to provide the service. Some studies (Ting and Schonfeld, Wang and Schonfeld) have been conducted to evaluate the performance between FCFS and SPF at single waterway lock or in waterway network. A fairer SPF (FSPF) has also been proposed to consider the fairness constraint (Ting and Schonfeld, Wang and Schonfeld).

SPF (Shortest Processing Time First)

Based on the definition, Shortest Processing Time First operation might select the tow based on the “average service time tow”. The tow with the lowest service time (usually the smallest tow) has the first priority to be processed. However, with different tow sizes, measuring the service or delay times per barge should be better than per tow due to the size variations. Thus, the SPF in current model is designed to assign the tow with minimum service time per barge (i.e. usually the largest tow) rather than the minimum service time per tow (i.e. the smallest tow). The SPF operation logic is shown in Figure 2. The SPF factor is calculated based on the average service time per barge.

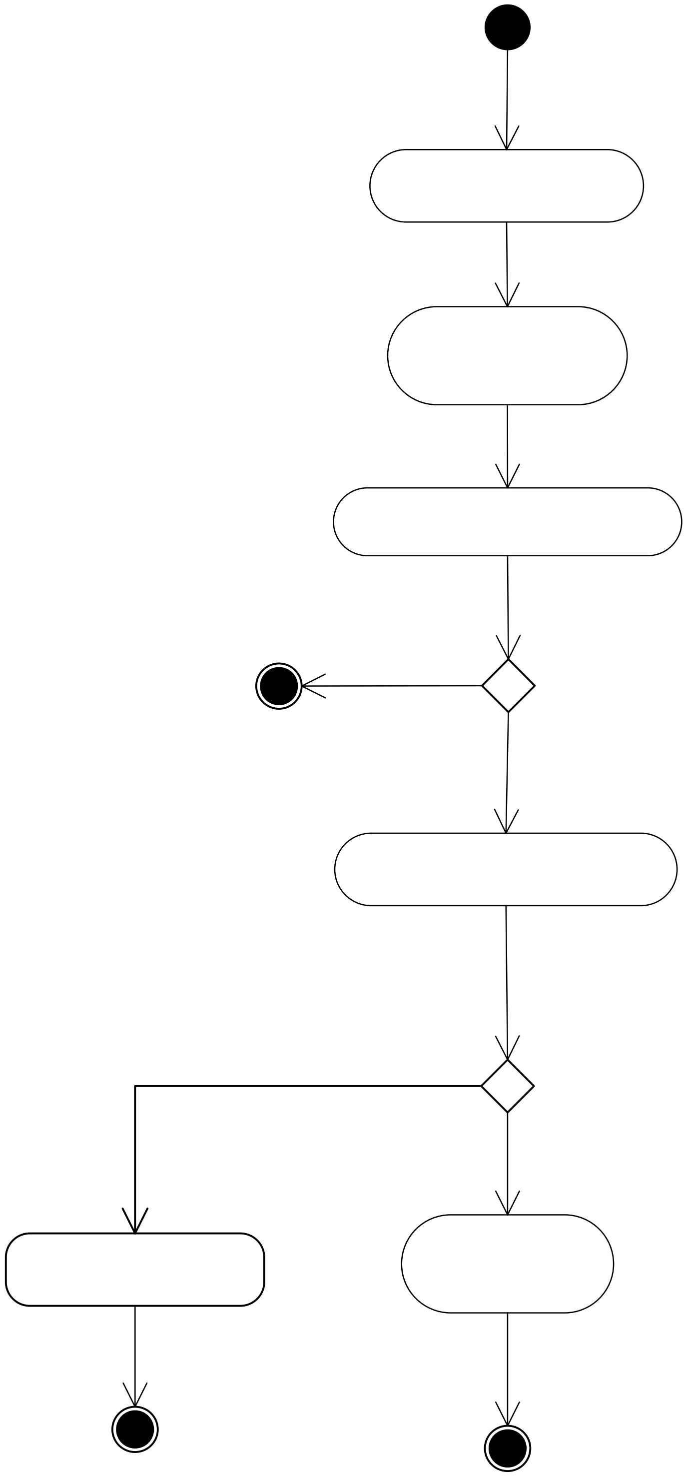


Figure 2 Operation Logic for SPF Control

The SPF assumptions are as follows:

1. Shortest processing time records the ‘shortest service time per barge’ and assigns the available chamber to this tow; however, all exclusive rules should be considered.

2. For the same number of cuts, a tow with more barges has higher priority than one with fewer barges.
3. For different numbers of cuts, we need to estimate the total incremental chamber turnback time for tows with more cuts; furthermore, we can calculate the average service time per barge for each tow and determine which tow should be served next.
4. If there are multiple vessels with the same SP time, then we select the next vessel based on the FIFO operation rule.

In the current DLM, the processing time is determined by the number of cuts. Therefore, the tow with the fewest cuts has the highest priority with the SPF policy.

FSPF (Fairer Shortest Processing Time First)

From the system point of view, SPF can save more system total delays through the pre-specified dispatching priority. However, small tows may experience more delays with SPF than FCFS. In order to balance the system efficiency and fairness among individual tows, FSPF is proposed to be intermediate between SPF and FCFS. FSPF is a fairer SPF control policy that gives priority to tows which have waited for a certain number of lockages (F*) based on the SPF rules. F* is the fairness value pre-defined in the input table. Different fairness values will influence the system performance. In general, if F*decreases, FSPF will be quite similar to FCFS. However, if F*increases, FSPF will be close to SPF.

Furthermore, the average number of tows in the queue is a significant indicator for evaluating the system. FSPF with lower fairness value gives smaller tows more chances to leave the waiting queues while they keep being passed by larger tows. Also, in the contrast, the system will be more efficient with lower barge delays and shorter barge queues based on the higher F*. All other assumptions of FSPF are similar to those of SPF. The FSPF operation logic is shown in Figure 3.

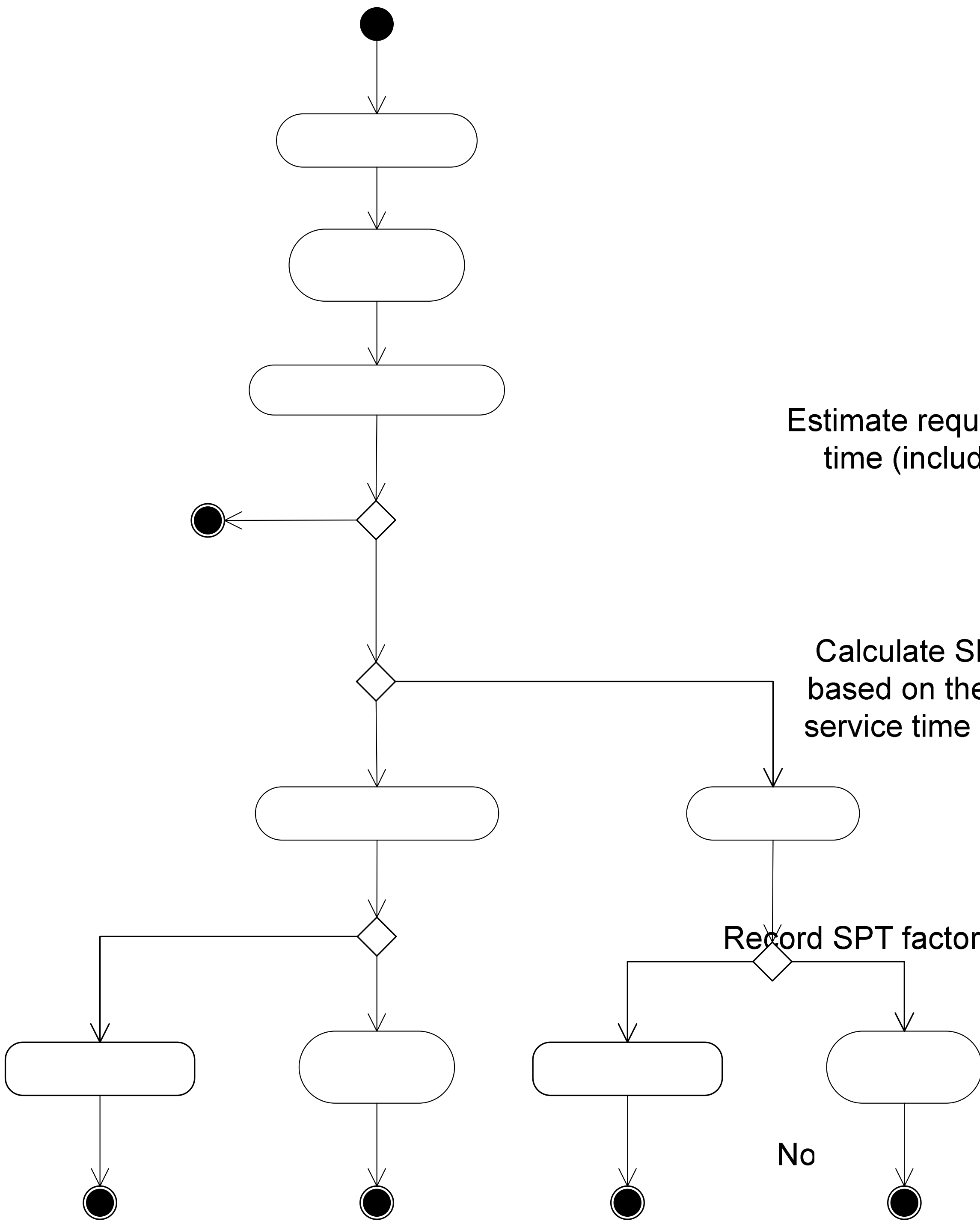


Figure 3 Operation Logic of FSPF Control

Scheduled Maintenance Closure

The user can set a scheduled outage as either a one-time or an annual recurring event, with a start date and duration. In the current Phase 2, we consider chamber-level outage instead of component-level outage. Table 11 shows the historical data for scheduled outage. The column of "RecurrencePeriod" can be used to determine whether the specific outage is a one-time or an recurring event. If the recurrence period is 0, it is a one-time outage. If the recurrence period is *t*, *t* is greater than 0, it is an recurring outage which occurs every *t* hours.

Table 11 Scheduled Outage

	ScheduledOutageID	ChamberID	OutageStartDate	OutageDuration	RecurrencePeriod
1	1	83	2007-03-08 12:01:00.000	0.666666666666667	0
2	2	83	2007-03-29 00:50:00.000	0.483333333333333	0
3	3	83	2007-05-14 12:59:00.000	0.916666666666667	0
4	4	83	2007-05-29 11:01:00.000	0.883333333333333	0
5	5	83	2007-05-29 12:16:00.000	0.9	0
6	6	83	2007-05-31 11:45:00.000	5.08333333333333	0
7	7	83	2007-12-14 14:41:00.000	1.31666666666667	0
8	8	83	2007-12-20 02:37:00.000	6.45	0
9	9	83	2007-12-28 04:35:00.000	3.56666666666667	0
10	10	83	2007-12-31 07:10:00.000	2.98333333333333	0
			....		
35	35	84	2007-03-28 08:56:00.000	0.716666666666667	0
36	36	84	2007-05-29 07:25:00.000	1.75	0
37	37	84	2007-05-29 09:30:00.000	3	0
38	38	84	2007-02-20 08:31:00.000	0.883333333333333	0
39	39	84	2007-02-21 09:09:00.000	1.91666666666667	0
40	40	84	2007-06-12 21:36:00.000	1.13333333333333	0
41	41	84	2007-12-31 06:05:00.000	4.06666666666667	0
42	42	84	2007-11-19 11:26:00.000	0.9	0
43	43	84	2007-12-09 23:30:00.000	3.58333333333333	0
44	44	84	2007-12-10 05:45:00.000	0.416666666666667	0

Operation Logic

In DLM, chambers are open or close for the service based on the scheduled outage table input by user. The time points (e.g., start time and end time, which can be calculated with the outage start time and outage duration) are marked during the simulation. Start and end events for an outage are pushed onto simulation event list. When the chamber is closed on schedule, the chamber will be set out of service after it finishes serving the vessels that have already started to be served. Those vessels that have been assigned to this chamber but are waiting at the approach point because of interference or other reasons will be released to the lock queues so that they can be re-assigned to other open chambers. When the chamber is back of service after repair, it will look for the next vessel in the lock queue to start its service again.

Navigable Pass

A navigable pass occurs at some locks based on the water levels and seasonal factors if locks are able to provide those types of lockages. Some locks, such as L&D 52 and L&D 53 on the lower Ohio River have movable wicket dams; others have relatively low fixed crest dams. These dam types afford vessels the opportunity to move past a lock site without actually locking through the lock chambers. They pass by the lock by navigating over the dam, hence the term navigable pass. Whether a vessel can pass a lock using a navigable pass or must lock through the chambers depends on water levels. The lock may be in navigable pass for weeks on end, or it may alternate between locking and navigable pass several times in one week. Historic LPMS/OMNI data can provide statistics which describe which times of the year navigable pass is likely to occur, and how long is it likely to last.

In DLM, the navigable pass schedule is given at the specific lock (as shown in Table 12), a navigable pass is likely to occur at these identified locks with specified points in time that navigable pass begins and ends. When the simulation runs to the start time of navigable pass, the navigable pass mode at this lock is on and all the vessels in queue then use the navigable pass over the dam. If there is vessel in the middle of regular lockage (of approach, entry, chambering or exit), the lockage process will be completed regardless the navigable pass period. DLM allows vessels in queue start navigable pass only after the regular lockage process for the previous vessel is completed. Thus, although the navigable pass mode is on, vessels in queue should start their navigable pass only right after the previous vessel's end of exit.

Table 12 Navigable Pass Schedule

	NavigablePassScheduleID	LockID	NavigablePassStartTime	NavigablePassEndTime
▶	1	54	1/2/2007 12:00:00 AM	1/3/2007 12:00:00 PM
	2	54	3/3/2007 12:00:00 AM	3/4/2007 12:00:00 PM
	3	54	5/5/2007 12:00:00 AM	5/7/2007 12:00:00 AM
	4	54	7/10/2007 12:00:00 AM	7/11/2007 12:00:00 AM
	5	54	9/20/2007 12:00:00 AM	9/21/2007 12:00:00 AM
	6	54	11/27/2007 12:00:00 AM	11/28/2007 12:00:00 AM
	7	54	12/7/2007 12:00:00 AM	12/10/2007 12:00:00 AM
*	*NULL*	*NULL*	*NULL*	*NULL*

When a lock is in navigable pass mode, processing time distributions are needed for upbound and a downbound vessels. Those distributions are provided in tblChamberOpsLevel10 with lockage type "N". With a navigable pass, vessels pass over the dam without any assigned chamber. There is no extra cut for any vessel. Therefore, although the processing time distributions provided in tblChamerOpsLevel10 are chamber-based, they are the same for both chambers (as shown in Table 13). If there are vessels in the queue, they will be removed from it based on either a FIFO or an N-Up M-Down policy. Since there is no detailed lockage components for navigable pass, all the component-based distribution (such as approach, entry, chambering and exit) are 0s and only overall processing time for navigable pass is counted.

Table 13 Processing Time Distributions for Navigable Pass

	AssistLevel	ChamberID	vesselTypeID	LkgType	TotalCutsRequired	Cut	IsPrimary	UpProcessTime	DnProcessTime
1	0	83	10	N	1	F	1	465	466
2	0	84	10	N	1	F	1	465	466
3	0	83	11	N	1	F	1	465	466
4	0	84	11	N	1	F	1	465	466
5	0	83	4	N	1	F	1	465	466
6	0	84	4	N	1	F	1	465	466
7	0	83	15	N	1	F	1	465	466
8	0	84	15	N	1	F	1	465	466

Operation Logic

In DLM, the navigable pass mode is switched on and off at the time points (e.g., start time and end time) input by user. Start and end events for a navigable pass are pushed onto simulation event list. When a navigable pass starts, vessels "assigned to available chambers" will be released back to lock queue with other "unassigned" vessels in queue. It should be noted that during a navigable pass, there is no service priority among vessels. That is, government vessels, recreational craft or commercial tows are considered together in the lock queue and served based on their arrival orders.

Figure 4 first shows how the navigable pass is considered in DLM when a vessel arrives at a lock. Since only "Start of Lockage" and "End of Lockage" are recorded for navigable pass, there are other detailed lock events in between SOL and EOL for any navigable pass vessel.

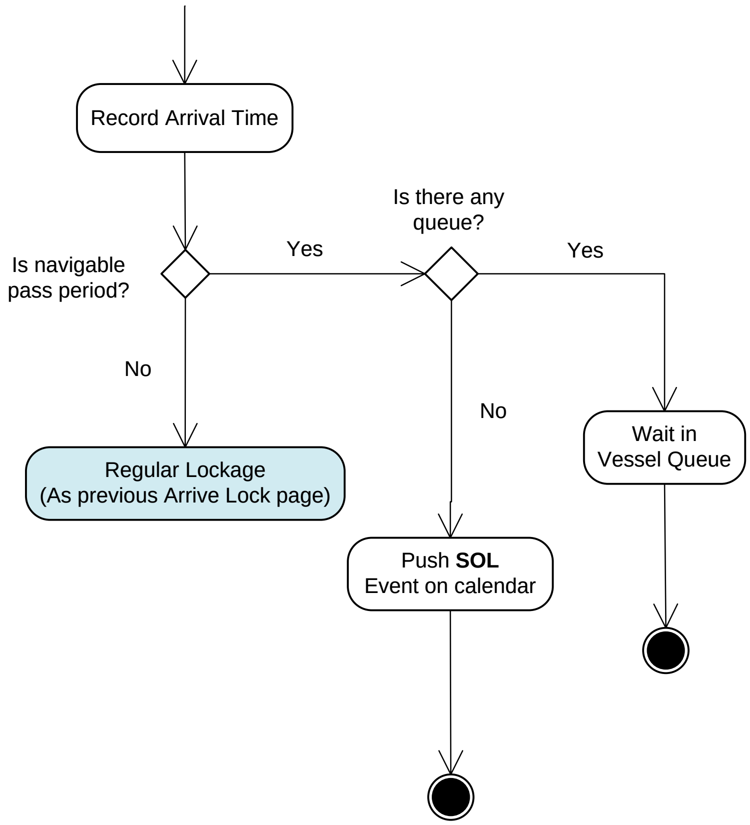


Figure 4 Arrive Lock for Navigable Pass

In DLM, if there are no more lockage components for navigable pass, the process of "look for next vessel" will be omitted in the events of end of entry and end of chambering (as shown in Figure 5 and Figure 6).

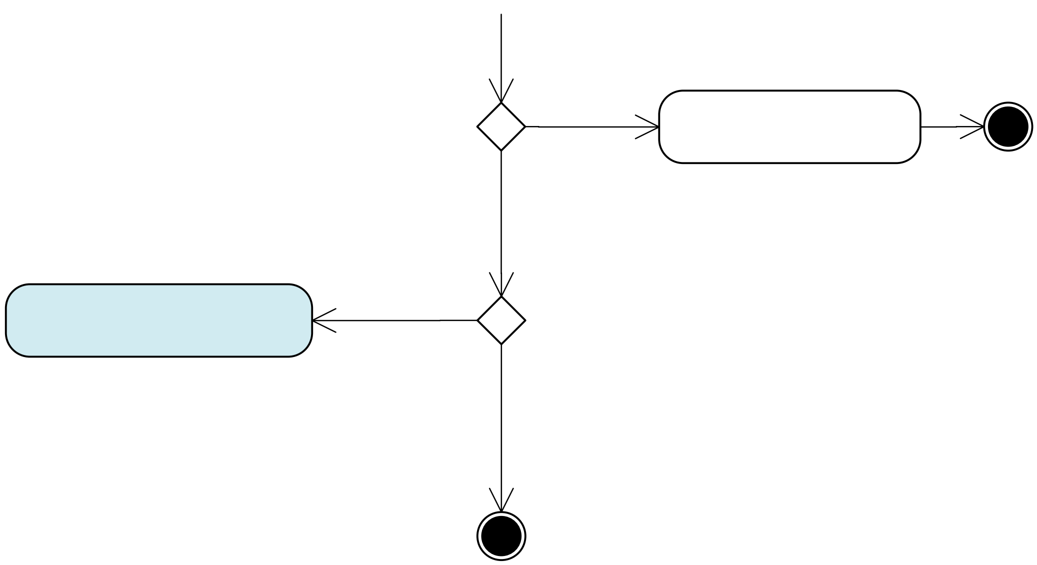


Figure 5 End of Entry for Navigable Pass

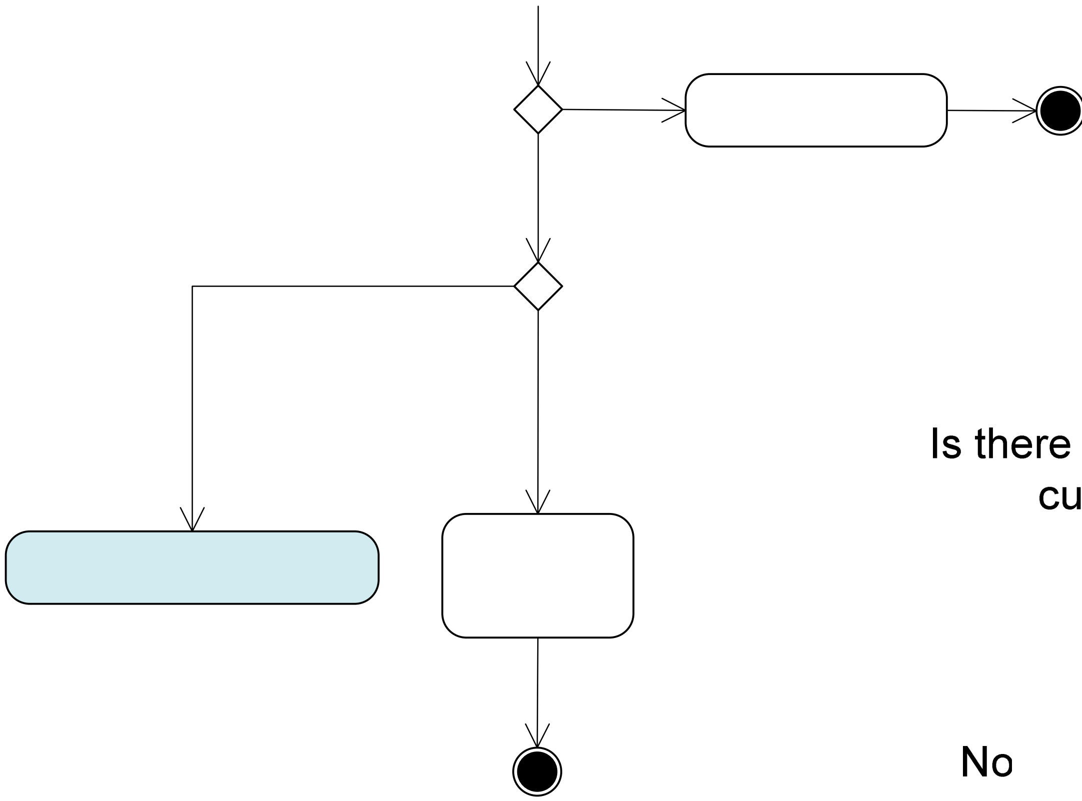


Figure 6 End of Chambering for Navigable Pass

The navigable pass mode might be on when a vessel is still using the regular lockage process, “straight lockage”. Therefore, it is necessary to check the exit type of the “last vessel” using a regular lockage. If the next vessel in the queue travels in the opposite direction of the “last vessel”, DLM resets the exit type of the last vessel with a fly exit (rather than exchange exit) since the next vessel is going to use the navigable pass. If the next vessel in the queue moves in the same direction, the last vessel is in its turnback exit and the next vessel starts its pre-approach. In this case, DLM will complete one more lockage for the next vessel, which has started its pre-approach and completes its lockage with a fly exit, before starting a navigable pass.

Figure 7 shows how the navigable pass is considered when a vessel is making the fly exit (or a recreational craft reaches its end of lockage).

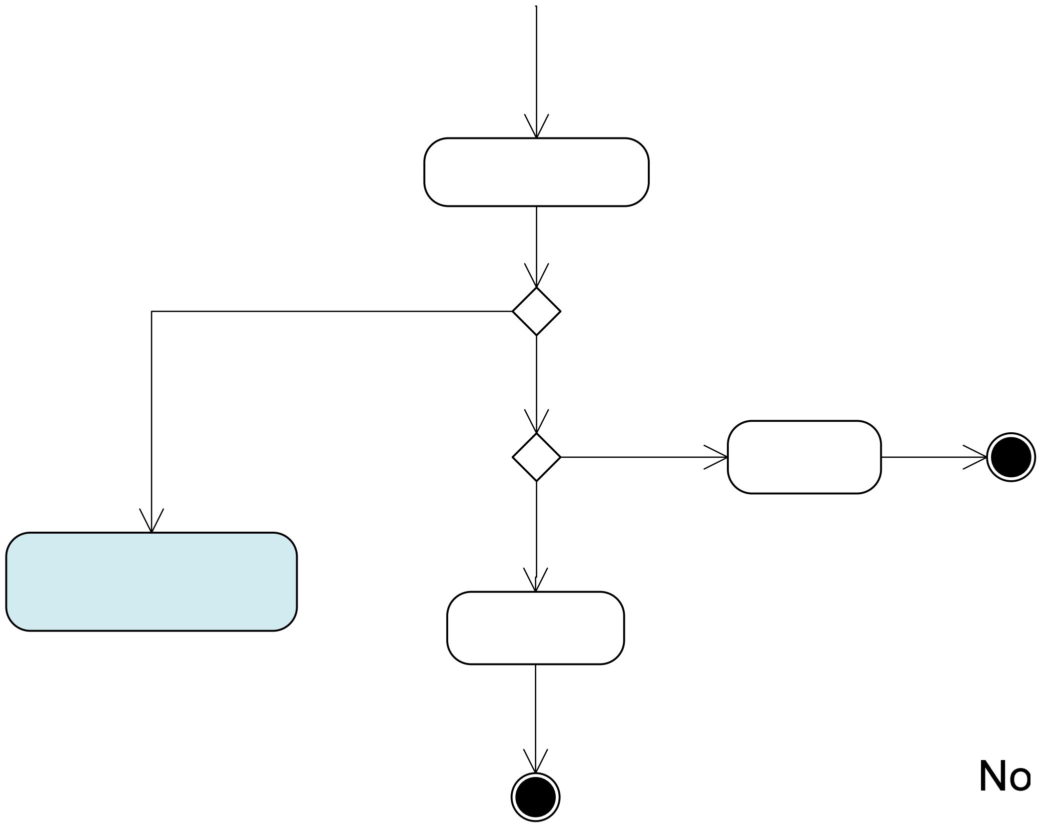


Figure 7 End of Fly Exit / Rec. EOL for Navigable Pass

Open Pass

Another specialty type of lockage involves open pass lockage. During this lockage type, water levels are such that the upper pool and lower pool have essentially the same elevation. In this case, the upper and lower gates of a lock chamber are kept in the open position, and a vessel travels through the chamber without a "chambering" event. These events are usually quite rare, but they may be more frequent at tidal locks. The DAPP must be able to determine statistics that describe open pass events, and the detailed lock model must be able to switch from locking mode to open pass mode. When in open pass mode, the chamber will use normal approach, entry and exit times, but the chambering time will be equal to zero. Since the processing time distributions for open pass lockage (approach, entry and exit only) may not be currently available, current developed DLM does not perform open pass lockages.

Multi-cut Lockage Efficiency Enhancements

Using Efficiency Enhancement Equipments

Since the locks on the waterway can hold only eight jumbo (35 ft. × 195 ft.) barges plus a towboat, when a tow with more than eight barges reaches a lock, the towboat must split the tow into units or "cuts" that fit the lock. The towboat must lock through with the first cut, push it out of the lock, and then lock back through to get the second cut of barges.

Help Equipment

(1) Tow Haulage

Tow haulage is a procedure for drawing barges through a lock by using equipment on the lock itself to minimize the maneuvering of a towboat when a tow exceeds the length of the lock. Tow haulage equipment on a lock can pull the first cut through by itself, so that the towboat can stay in its original pushing position and lock through with the second cut.

Lock operation for oversize tows is more efficient with tow haulage equipment. Towboats are used more expeditiously, and shippers can take advantage of the economy of large tows. Larger tows represent a potential for significant cost reduction for both shippers and their customers. Tow haulage equipment has been installed at twelve locks on the McClellan-Kerr in Arkansas. (http://www.swl.usace.army.mil/navigation/mckarns.html#haulage)

(2) Helper Boats

Self-help is referred to as "industry self-help". Self-help means that tow operators at a lock help each other. They do this by having a volunteer boat come up on the exiting end of the lockage and serve as a boat that pulls cuts. This is faster than tow haulage and they can get the cut further away from the gate.

Sometimes, the lock provides helper boats. The helper boat, usually a low-power, typically 800 horsepower towboat (push boat) used to assist tows approach to a lock chamber, pull the unpowered cut to the end of the guidewall during a multi-cut lockage, remove ice and debris from the lock approach and chamber, and provide emergency assistance.

The time saving gained from a helper boat varies based on location, flow conditions, weather and other factors. Under normal flow conditions at most Upper Mississippi River sites, initial study analysis indicates a saving of approximately 5-to-15 minutes per lockage; in contrast, the Illinois Waterway locks typically report limited or no time savings. However, on both rivers, greater time savings are gained during high water flows. Additional time savings can be gained by also using helper boats to pull the first cut to the end of the guidewall so that a 1,200-foot tow can be reattached outside of the chamber.
(UMR-IWW System Navigation Study Newsletter, January 1997, Vol.4 No.1)
(http://www2.mvr.usace.army.mil/UMRS/NESP/Documents/1997%20Jan%20Nav%20Study%20Newsletter.pdf.)

If self-help is used, interference would occur. Therefore, if both chambers are operable, the self-help might not be used. The boat providing the help would either cause gate interference while waiting for the next cut or it would cause both gate and approach area interference if it takes the cut somewhere "away" from the lock.

Schemes of Handling Extracted Cut

In order to consider the availability of assistance for cut extraction, a column of "HelpEquipment" should be provided in the table "tblChamber" as one of the chamber specifications. If it is checked, the help equipment at current chamber is available. In order to simplify the model, DLM first assumes that if help equipment is available at locks, it will be fully utilized and never sit idle for any period. That is, option of "with" or "without equipment" is considered while estimating the processing time for any lockage component.

Table 14 Chamber Specification for Vessel Assistance

	ChamberID	Lock...	ChamberDesc	Main	Length	Width	Assistance	HelpEquipment
1	83	54	Marmet	1	1200	110	1	1
2	84	54	Marmet	0	360	56	1	0

Help equipment affects the processing time distributions. In the DLM model, the cut approach time is generated from the distribution of turn back approach time and the cut extraction time is generated from the distribution of turn back exit time. Since using help equipments can save processing times for multi-cut lockage, the processing time distribution for the intermediate cuts and the last cut with and without help equipments would be different. Therefore, an additional column of "AssistLevel" is added in the table "tblChamberOpsLevel10". Under the simplest case, with or without help equipment, if there is no available help equipment, "0" is indicated as "none" in column of "AssistLevel". If there is help equipment, value of "1" is given to "AssistLevel". In addition, it is noted that the help equipment is only used for multi-cut tows under regular lockage (straight lockage), but not other lockage or vessel types.

Table 15 Processing Time Distributions for Chamber with Vessel Assistance

	AssistLevel	ChamberID	VesselTypeID	LkgType	TotalCutsRequired	Cut	IsPrimary
1	0	83	11	S	1	F	1
2	0	83	11	S	2	F	1
3	0	83	11	S	3	F	1
4	0	83	11	S	2	L	1
5	0	83	11	S	3	L	1
6	0	83	11	S	3	I	1
7	1	83	11	S	1	F	1
8	1	83	11	S	2	F	1
9	1	83	11	S	3	F	1
10	1	83	11	S	2	L	1
11	1	83	11	S	3	L	1
12	1	83	11	S	3	I	1

In the future, the plan formulation hierarchy proposed by the Corps might be considered. The plan formulation hierarchy describes conceptually how the Corps organizes and conducts its studies. The entire plan formulation hierarchy of conducting studies might affect the future modification of *tblChamberOpsLevel12*.

The Corps plan formulation hierarchy can be diagrammed as:

- Study
    - Condition
        - Alternative
            - Measure

In many cases, the NaSS model will be used to conduct studies. There are many different kinds of studies, Reconnaissance, Feasibility, Major Rehab, O&M, Engineering, etc. There are many scopes of study. The Upper Mississippi-Illinois River Feasibility study covered a large number of locks spread over a wide geographic area with a huge array of alternative operational and construction options. Another large scale study was the Ohio River Main Stem Study, which considered every lock on the Ohio River. Smaller scale studies include the single lock feasibility studies at McAlpine, Marmet and Chickamauga to name a few. Even smaller scale are the Major Rehabilitation studies we conduct before major lock rehabilitation can proceed.

Most studies have at least two Conditions, namely With and Without Project. The Without Project Condition is the most likely future state of the system if improvements are not authorized. The Without Project Condition is used as the baseline against which With Project Condition Alternatives are measured.

Many studies have several different With Project Condition Alternatives and may have more than one Without Project Alternative. An example With Project Condition Alternatives may be to add another chamber at the project that is 600 feet long and 110 feet wide. Another alternative may be to add a 1200x110 chamber. Another alternative may be to extend the existing chamber from 360 feet long to 600 feet long. The initial list of With Project Condition Alternatives are usually selected early in the study process. As the study progresses, additional Alternatives may be added based on the information developed during the study.

Lowest in the study hierarchy are Measures. These may be thought of as Alternative tweaks, or alternatives within Alternatives. For example, the alternative may be to add a 600x110 chamber at a lock site. A measure may be to build the 600x110 with a wraparound around filling/emptying culvert system which has a design fill/spill time of 18 minutes. Another may be to have the filling/emptying system culverts within the lock wall monoliths with a fill/spill time of 9 minutes. These fill/spill designs would all be associated with the new 600x110 Alternative. The may be other measures associated with other Alternatives.

After all this background about the Corps Plan Formulation Hierarchy, the vessel and mechanical assists could possibly fit in at the Measures level. If we use the Marmet Feasibility Study as an example, vessel assists would be a Measure under an Alternative under the Without Project condition. Currently, they use mechanical assist to pull unpowered cuts from the chamber. An efficiency enhancement would be to encourage the towing industry to use self-help, which is a form of mechanical assist, whenever the queue length exceeds a threshold.

If we accept that mechanical assists are an Alternative Measure, the new tblChamberOpsLevel10 could possibly be like Table 16 with new columns of

“ConditionID”, “AlternativeID”, “MeasureID”, and “AssistLevel”. Those information indicate how the assistant level changes based on different condition, alternative and measures. In addition, the model needs to know whether one form of assist is more efficient than another. The threshold will be used by DLM to "go to a more efficient assist" or "go to a less efficient assist". However we need to tell it which set of distributions is more efficient and which is less.

Table 16 Chamber Operation Level Processing Time Distributions with Hierarchy

ChamberOpsID	ConditionID	AlternativeID	MeasureID	AssistLevel	ChamberID	VesselTypeID	LkgTyp
1	0	0	0	0	83	4	S
2	0	0	0	0	84	4	S
3	0	0	0	0	83	15	S
4	0	0	0	0	84	15	S
5	0	0	0	0	83	10	S
6	0	0	0	0	83	10	N
7	0	0	0	0	84	10	S
8	0	0	0	0	84	10	N
9	0	0	0	0	83	11	S
10	0	0	0	0	83	11	S
11	0	0	0	0	83	11	S
12	0	0	0	0	83	11	S

Serving Rec. Vessels during Chamber Turnback

Another way to increase the efficiency is locking through the recreation vessels during the chamber turnback between cuts of multi-cut lockage. That is, if a 2-cut tow is going downstream, a lock operator will allow upstream recreation craft to be served during the chamber turnback between the 1st and 2nd cuts. Detailed operation will be discussed in the later section on Multi-Recreational Lockage.

Multi-Vessel Lockage

The logic required to implement multi-vessel lockages is developed during this Phase 3. Multi-vessel lockages are those where two or more commercial vessels are served in a single lockage cycle. Only commercial vessels are considered in defining multi-vessel lockages. Recreation vessels are not commercial vessels. A typical multi-vessel lockage serves two small tows which fit in a large chamber, and are therefore, served at the same time. This “two vessel” limit is based on navigation in the Ohio River Basin, where multi-vessel lockages are composed of commercial tows.

However, at some locks, there do have more than two tows in a single chamber and it is possible to have three tows locked together. According to NaSS Schema, there are 20 locks in the nation with the greatest percent of multi-vessel lockages of 3 or more vessels per lockage. One can see there are only two locks where multi-vessel lockages of 3 or more vessels play a significant role (Mark Lisney, 2008).

Special rules and logic apply to multi-vessel lockages. A tow moving a hazardous commodity cannot partake in multi-vessel lockages. High priority vessels (including commercial passenger vessels), however, from the historical data, can be part of multi-vessel lockages.

Vessel Types

For NaSS purposes the LPMS definition of Multi-Vessel lockages is used here.

- Multi-Vessel Lockage - More than one commercial vessel is served in a single lockage cycle. A separate lockage log and vessel log is completed for each vessel served. Only *commercial vessels* are considered in defining multi-vessel lockages.

- Commercial Vessels - Not a field, but a description of a group of vessels. This group consists of Cargo Vessels, Liquid Cargo Vessels, Fishing Vessels, Dredge Vessels, Crewboat Vessels, Commercial Non-Cargo-Vessels, Passenger Boats or Ferries, Tow or Tug Boats, Federal Government Contractor Vessels, and Others. (See also *Non-Commercial Vessels*) (Vessel Types C, E, F, J, K, M, P, T, U, and Z).

- Non-Commercial Vessels - Not a vessel type but may be used as a category in reports. It consists of vessel types Recreational, Federal Government, and Non-Federal Government (Vessel Types R, G, and N).

Therefore, according to the LPMS definition, recreational boats, government vessels, and non-government vessels are not considered for multi-vessel lockages. Therefore, for NaSS modeling purposes, if two or more commercial vessels lock together, with or without additional non-commercial vessel(s), it is a multi-vessel lockage.

For packing multiple vessels (i.e., 2 or more tows) in one lockage, it is important to know the chamber size, required buffer distance and available space left for a 2nd vessel after the 1st vessel has been placed in the chamber. In order to simplify the processes of searching for the 2nd vessel and packing both vessels, it is assumed that vessel's dimension is measured by its maximum length. That is, as shown in Figure 8, the available space left for the 2nd vessel is calculated based on the chamber length, 1st vessel's maximum length (after reconfiguring it with the most condense way) and required buffer distance. With the information about the available space for the 2nd vessel, the DLM model searches through the queue of tows to locate the candidate vessel as the 2nd vessel. The search length is limited. If there is no qualified vessel among the search-length queue, the model then performs a "straight" lockage for the 1st vessel only instead of a multi-vessel lockage. It is possible to have a "straight" lockage with mixed vessels, as discussed later.

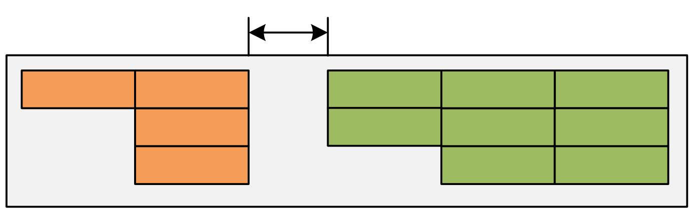


Figure 8 Multi-Vessel Lockage for Two Tows

Input Requirement

Generally, there needs to be a significant distance, say 100-200 feet, between the vessels while they are in the chamber. If the queue is very long, say 25 vessels in each direction, the logic should not search through the entire queue looking for small vessels to make up multi-vessel lockages. The depth of the queue search and the buffer distance is user-definable. As shown in Table 17, columns of "MultiVesselMax", "QueueSearchDepth" and "BufferDistance" are used to support the operation of multi-vessel lockage. The column of "MultiVesselMax" is used to indicate the maximum number of vessels which can be served together in one lockage. A value of 3 means that at most 3 vessels are able to participate the multi-vessel lockage together. The minimum value of this column is 1, which means at least one vessel can be locked in one lockage. That is, value of 1 or less indicates that the multi-vessel lockage is not allowed in the specific chamber; value or 2 or more indicates that the multi-vessel lockage is allowed in the specific chamber.

Table 17 Chamber Specifications for Multi-Vessel Lockage

	ChamberID	Lock...	ChamberDesc	Main	Length	Width	MultiVesselMax	BufferDistance	QueueSearchDepth
1	83	54	Marmet	1	1200	110	3	20	10
2	84	54	Marmet	0	360	56	1	20	5

In addition, since it is important that a tow carrying hazardous commodities cannot be chambered with other vessels, the relevant information can be checked from "CommodityID" in *tblBargeTransaction* and "CommodityCode" as well as "IsHazardous" in *tblCommodity*. If a tow is moving hazardous materials in any one of its barge sets (a tow might have more than one barge set), it cannot participate in a multi-vessel lockage. Similarly, if a tow waiting in queue carries hazardous materials, it cannot be selected to be packed into a multi-vessel lockage.

Table 18 Commodity

	CommodityID	CommodityName	CommodityCode	ISHazardous
	1	Units(Ferried AutosPassengersRailway Cars)	00	False
	2	EMPTY	01	False
	3	CoalLignite & Coal Coke	10	False
	4	Petroleum and Petroleum Products	20	True
	5	Crude Petroleum	21	True
	6	Gasoline Jet Fuel Kerosene	22	True
	7	DistillateResidual & Other Fuel Oils	23	True
	8	Petroleum PitchesCokeAsphaltNapthaSolvents	24	True
	9	Petroleum Products NEC	29	True
	10	Chemicals and Related Products	30	True
	11	Fertilizers	31	True
	12	Other Chemicals and Related Products	32	True
	13	Crude Materials Inedible Except Fuels	40	False
	14	Forest Products Lumber Logs Woodchips	41	False
	15	Pulp and Waste Paper	42	False
	16	SandStoneLimestoneSoilDredged Mat.	43	False
	17	Iron Ore and Iron & Steel Waste & Scrap	44	False
	18	Marine Shells	45	False
	19	Non-Ferrous Ores and Scrap	46	False
	20	Sulphur (Dry) Clay & Salt	47	False

Processing Time Estimation

With a multi-vessel lockage, extra time for each lockage component, if applicable, should be specified for each additional vessel. That is, there could be extra approach, entry, chambering and exit times if the additional vessel is added. The required additional time varies for different vessel types. Therefore, based on the vessel types (tow or high priority vessel), the time for each lockage component is estimated differently.

In the case of multi-vessel lockage, all the participating vessels are assumed to be small and one-cut vessels. *tblChamberOpsLevel10* provides the processing time distributions for each lockage components based on the chambers, vessel types and directions. Taking lockage component "Approch" as an example (as shown in Table 19), in addition to regular processing time distributions for "FlyApp", "ExchangeApp", or "TBApp", there are extra columns of "MultipleFlyApp", "MultipleExchangeApp" and "MultipleTBApp" used for additional approach time required for each additional vessel. That is, the approach time for the first vessel would be determined with the processing time distribution shown in the columns of "Approach"; the additional approach time while adding extra vessels would then be determined with the processing time distributions shown in the column of "MultipleApproach". Similar processing time estimates are applied to the other lockage components, "Entry", "Chambering" and "Exit".

Table 19 Processing Time Distributions

	ChamberID	VesselTypeID	LkgType	UpFlyApp	MultipleUpFlyApp	UpExchangeApp	MultipleUpExchangeApp	UpTBApp	MultipleUpTBApp
1	83	4	S	297	531	298	531	299	531
2	84	4	S	329	531	332	531	335	531
3	83	15	S	265	531	266	531	267	531
4	84	15	S	329	531	332	531	335	531
5	83	10	S	0	0	0	0	0	0
6	83	10	N	0	0	0	0	0	0
7	84	10	S	0	0	0	0	0	0
8	84	10	N	0	0	0	0	0	0
9	83	11	S	127	531	130	531	133	531
10	83	11	K	199	531	199	531	209	531
11	83	11	N	0	0	0	0	0	0
12	84	11	S	329	531	332	531	335	531
13	84	11	K	329	531	332	531	335	531
14	84	11	N	0	0	0	0	0	0
15	83	11	S	127	531	130	531	133	531
16	83	4	N	0	0	0	0	0	0
17	84	4	N	0	0	0	0	0	0
18	83	15	N	0	0	0	0	0	0
19	84	15	N	0	0	0	0	0	0

Operation Logic

If multi-vessel lockage is allowed at a lock, the lock operator looks for 2nd vessel for multi-vessel lockage at the time of the 1st vessel starts its lockage. That is, at the time of vessel start its exchange / turnback approach, the possibility of packing multiple vessels is considered if this vessel does not carry hazardous material (as shown in Figure 9). If multiple vessels are found, the extra approach time (if there is) should be added for each extra vessel.

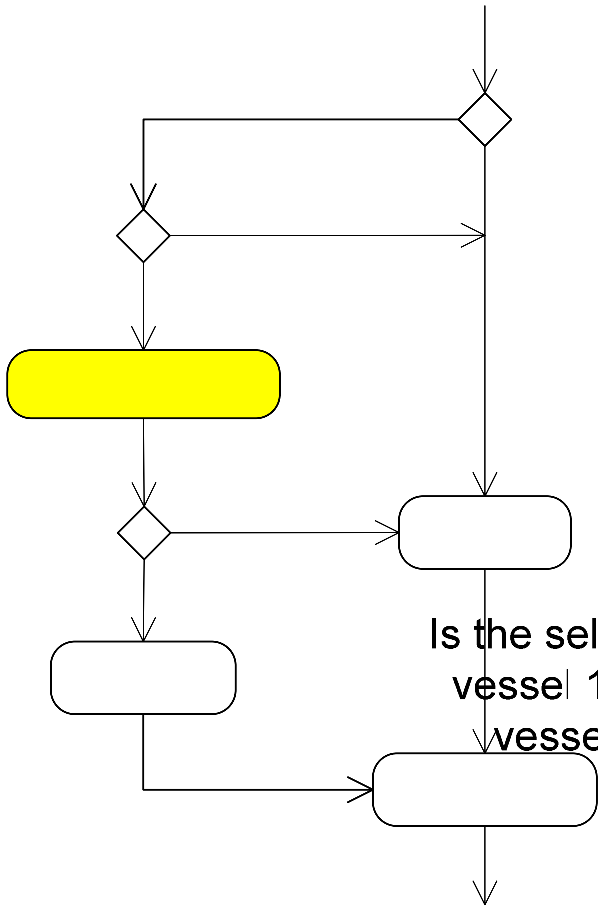


Figure 9 Consider Multiple Vessels at the Start of Approach

Similarly, if multiple vessels are in one lockage, extra entry time, extra chambering time, or extra exit time should be added for each extra vessel if they are applicable (as shown in Figure 10).

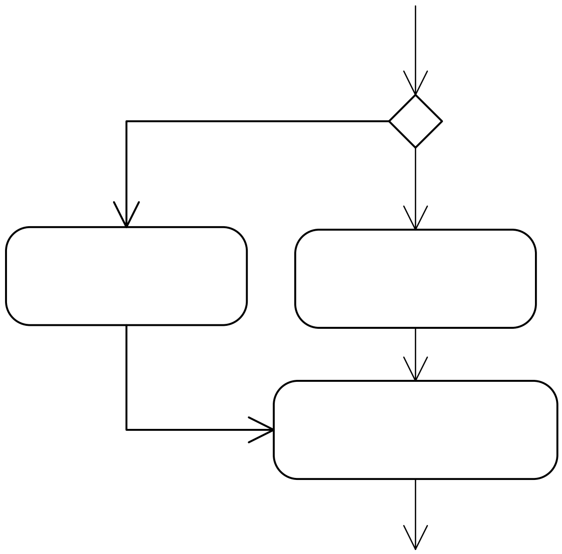


Figure 10 Extra Entry/Chambering/Exit Time for Multiple Vessels

Figure 11 shows the logic of considering multiple vessels. A lockage with multiple vessels could be a multi-vessel lockage (according to the definitions) or a mixed-vessel lockage (as discussed later). Figure 12 further shows the procedures of multi-vessel lockage.

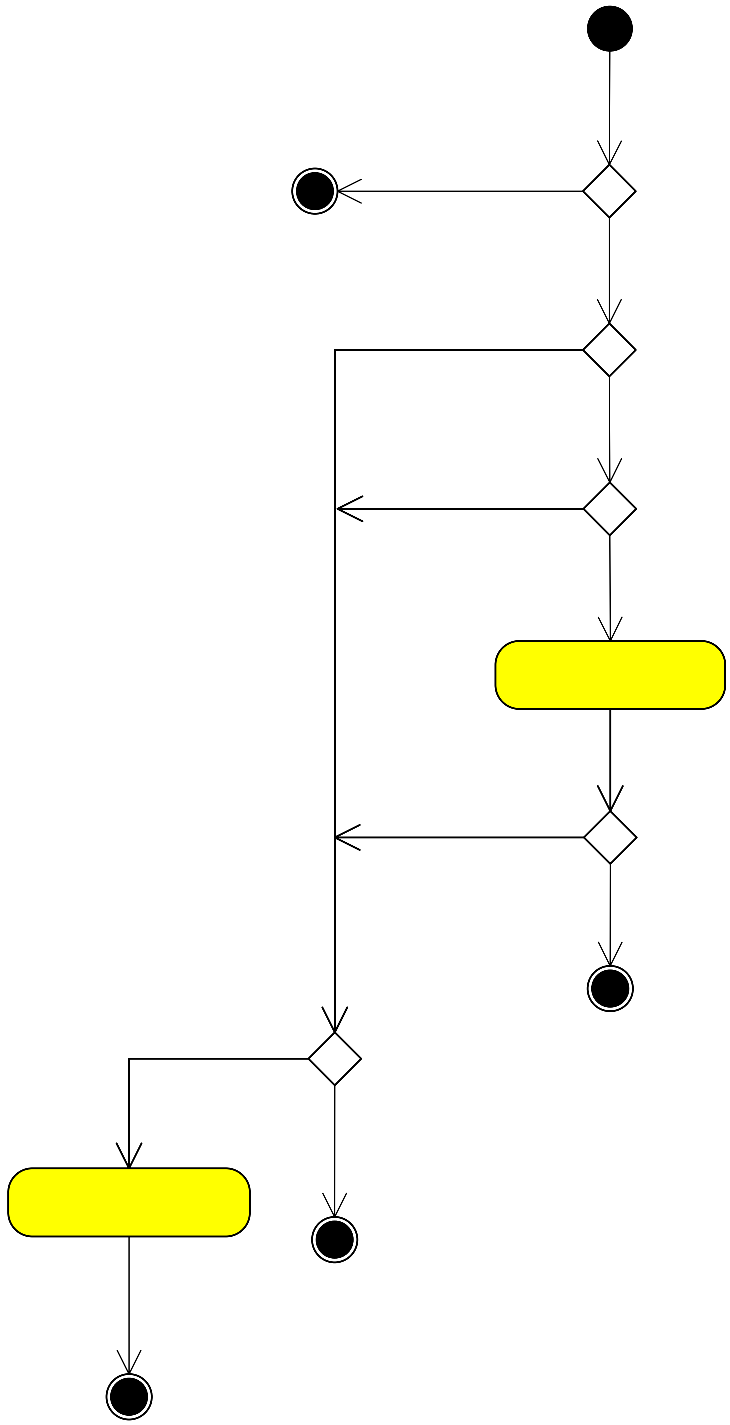


Figure 11 Consider Multiple Vessels

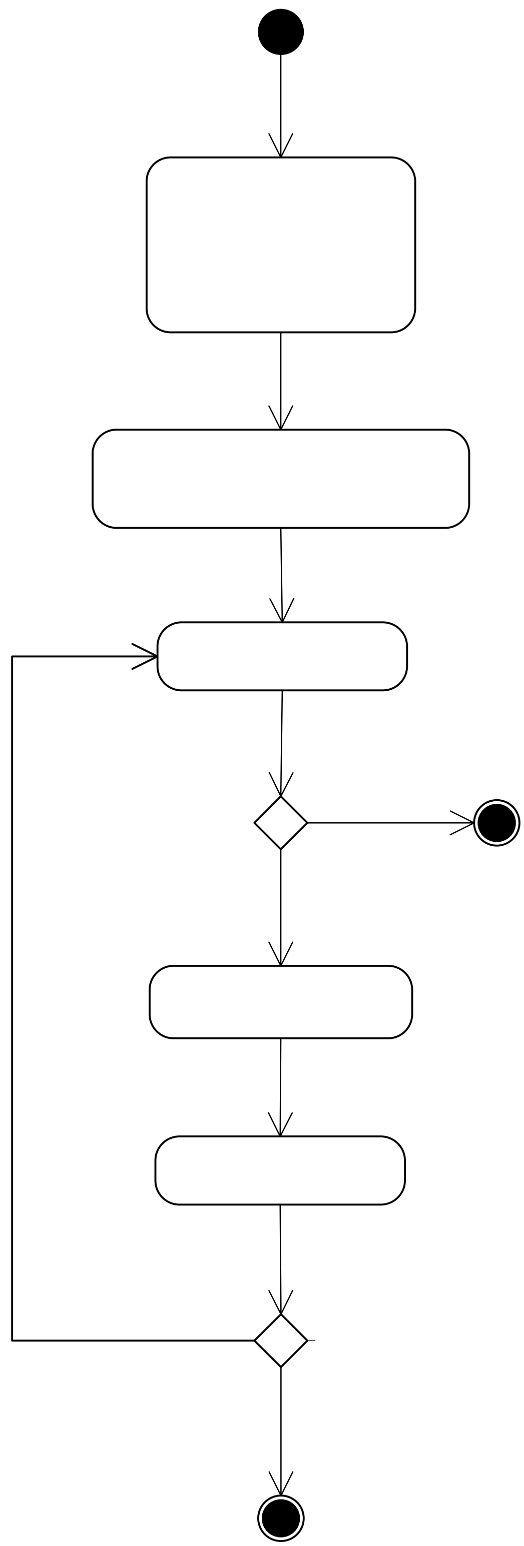


Figure 12 Multi-Vessel Lockage

Mixed-Vessel Lockage

Although a multi-vessel lockage must, by definition, include only commercial vessels, other lockage types do occur. For example, a tow and one or more recreation craft may lock together. In addition, light boats are quite small and are highly like to be locked together or with a tow. Since those lockages are recorded not as multi-vessel lockages, but with the same designation they would be given if the extra vessels weren't present, DLM then models those lockages as mixed-vessel lockages.

Vessel Types

From the previous section, according to the LPMS definition, recreational boats, government vessels, and non-government vessels are not considered for multi-vessel lockages. Therefore, for NaSS modeling purposes, if two or more commercial vessels lock together, with or without additional non-commercial vessel(s), that is a multi-vessel lockage.

- If one commercial vessel locks with one or more non-commercial vessels, that is a MIXED VESSEL LOCKAGE.

- If two or more non-commercial vessels lock together without a commercial vessel, that is a MIXED VESSEL LOCKAGE.

Similarly to multi-vessel lockages, buffer distances between vessels must be maintained (as shown in Figure 13). The buffer distance is defined by user, and the user has the option to activate these mixed vessel type lockages. However, different from multi-vessel lockage, there is no queue search limit in mixed-vessel lockage. All the non-commercial vessels in a queue can be locked together as long as they can fit into the chamber.

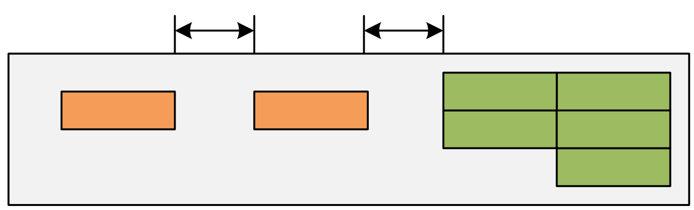


Figure 13 Mixed Vessel Locakge for Tow and Light Boat (or Recreational craft)

Locking recreational vessels in group (discussed in next section) is also considered as mixed-vessel lockage. The only difference is that if the first vessel is recreational, the other recreational vessels in queue will be packed together in one lockage up to the space limit. No other non-commercial vessels would be participated in this specific lockage for group of recreational vessels. However, if the first vessel is non-recreational, all other non-commercial vessels, including recreational vessels, in the queue are able to participate the mixed-vessel lockage as long as there is enough space in the chamber.

Input Requirement

As in mixed vessel lockage, there still needs to be a significant distance between the vessels while they are in the chamber. However, there is no restriction for the depth of queue search in the mixed-vessel lockage. As can be seen, the column of "MixedVesselAllowed" in Table 17 is used to indicate mixed-vessel lockage.

Table 20 Chamber Specification for Mixed-Vessel Lockage

	ChamberID	LockID	ChamberDesc	Main	Length	Width	MixedVesselAllowed	BufferDistance	AdditionalVesselsPer100Ft
1	83	54	Marmet	1	1200	110	1	20	10
2	84	54	Marmet	0	360	56	1	20	10

In addition, mixed-vessel lockage is also operationally different from multi-vessel lockage, in addition to different vessel type and different number of vessels which can be locked together. In multi-vessel lockage, two vessels are lined up to fit in chamber with considered buffer distance in length. However, in mixed-vessel lockage, more than two small vessels (e.g. group of recreation vessels) can be packed together. Those vessels are not just lined up, but may also possibly be beside each other (as shown in Figure 14).

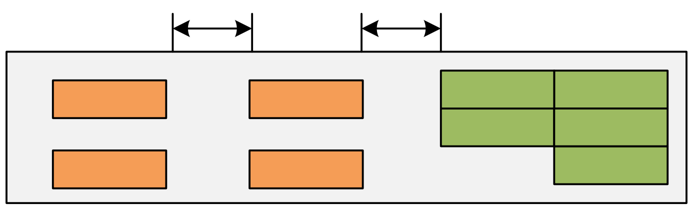


Figure 14 Mixed-Vessel Lockage for Group of Recreational Craft

Unlike multi-vessel lockage with specified maximum number of vessels per lockage, mixed-vessel lockage aims to accommodate as many vessels as will fit. Sometimes 25 recreational vessels can be packed together in one lockage. Since recreational vessels are able to participate the mixed-vessel lockages, a simplified assumption is considered to pack group of recreational vessels without detailed vessel dimension information for each individual one. Therefore, the column of "AdditionalVesselsPer100Ft" in Table 17 is used to indicate the number of recreational vessels which can be approximately fitted for a certain length of chamber.

Processing Time Estimation

Similar to multi-vessel lockage, the time required for each additional vessel to join the lockage is added to each lockage components, if there is. The columns of

Buffer

“Multiple” (as shown in Table 19) in *tblChamberOpsLevel10* are used for the additional vessels.

Operation Logic

If mixed–vessel lockage is allowed in the chamber, as long as no hazardous materials are carried, all vessel types can be locked together if there is enough space. It also follows the limitation in *tblVesselTypePolicy* (as shown in Table 21). That is, as long as a specific vessel type is not allowed in the chamber, this vessel type is not allowed in a mixed vessel lockage.

Table 21 Vessel Type Allowable in Specific Chamber

	VesselTypePolic...	ChamberID	VesselTypeID	VesselPolicyDescription	WaitLockage	AllowInChamber	AllowInTurnback
▸	1	83	10	No Wait Recreation Vessel	0	False	False
	2	84	10	Wait Three Recreation Vessel	3	True	True
	5	83	15	No Wait LightBoat	0	True	True
	6	84	15	No Wait LightBoat	0	True	True
*	NULL	NULL	NULL	NULL	NULL	NULL	NULL

There could be more than one light boat or recreational vessel to be packed with commercial tow if mixed vessel lockage is allowed. Figure 15 further shows the logic of mixed vessel lockage.

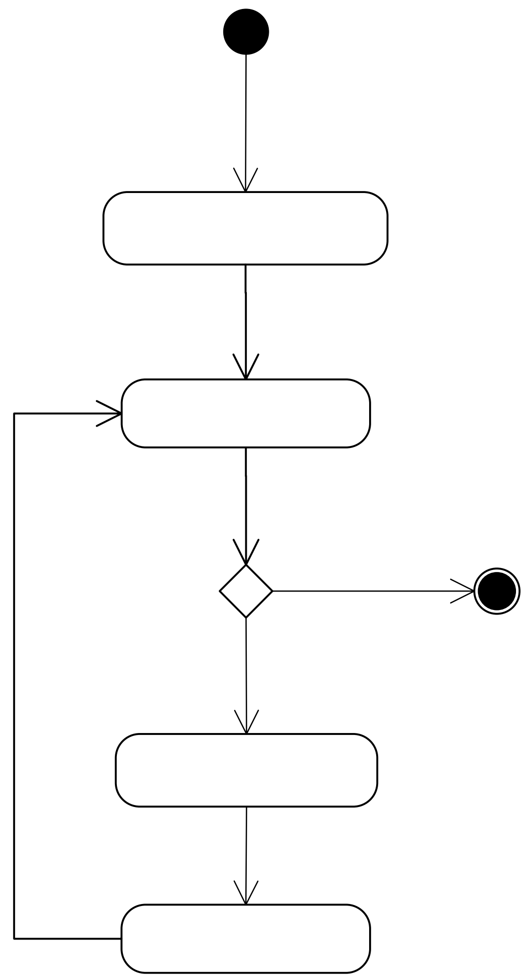


Figure 15 Mixed-Vessel Lockage

Lockage for Multi-Recreational Craft

As discussed in the Phase 2 report, there are special policies for recreational vessels, such as waiting for commercial lockages and exclusive serving periods. In addition to those rules applicable only for recreational vessels, those recreational vessels are usually locked together in groups as long as the chamber is able to accommodate them. Therefore, there is an option of locking recreational vessels individually or as a group. As discussed in the previous section, locking a group of recreational vessels is one type of mixed-vessel lockage. As long as the user indicates the column of "MixedVesselAllowed" in tblChamber (as shown in Table 20), the policy is applicable to recreational vessels. In addition to the lockage for multiple recreational vessels, there are other rules applicable to recreational vessels, as well as other vessels. Thus in order to possibly extend the rules to other vessels in future, a policy table for various vessel types, *tblVesselTypePolicy* (as shown in Table 22), is created.

Usually, recreational vessels can be made to wait for n (e.g. n=3) commercial lockages before being served. Recreational vessels which have waited for n or more commercial lockages have higher priority to be served by chambers than commercial tows. Based on the applicability of mixed-vessel lockage, when there is a recreation lockage, all the recreational vessels in the queue should, if possible, be locked together regardless of how many commercial lockages other recreation vessels have waited for.

Table 22 Table of Vessel Policy

	VesselTypePolic...	ChamberID	VesselTypeID	VesselPolicyDescription	WaitLockage	AllowInChamber	AllowInTurnback
▶	1	83	10	No Wait Recreation Vessel	0	False	False
	2	84	10	Wait Three Recreation Vessel	3	True	True
	5	83	15	No Wait LightBoat	0	True	True
	6	84	15	No Wait LightBoat	0	True	True
*	NULL	NULL	NULL	NULL	NULL	NULL	NULL

There might be some restrictions at chambers to some specific vessel types. This consideration is indicated in the column of "AllowInChamber". At some locks in Ohio River, recreational vessels are not allowed in the main chamber even though it is available for lockage service.

In addition to the issue of "chamber exclusion", there is another consideration of "chamber preference" for various vessel types. That is, some chambers are "preferred" for some vessels. If preferred chambers are not available, vessels can use non-preferred chambers as long as they are "allowed" to use them. Table 23 is used to define the issue of "chamber preference". There could be a list of chamber preference for various kinds of vessels. It is noted that any single vessel type can only "favor" one chamber at one lock. It will be an illegal input entry if a specific vessel type "prefers" more than one chamber at a specific lock location.

Table 23 Chamber Preference

	VesselTypeChamberPreferenceID	LockID	ChamberID	VesselTypeID
▶	1	54	84	10
*	NULL	NULL	NULL	NULL

Since recreational lockage is viewed as one type of multi-vessel lockage, the column of "AdditionalVesselsPer100Ft" in Table 17 is also used to indicate the number of recreational vessels which can be approximately fitted for a certain length of chamber without detailed vessel dimension information for each individual one.

Multi-Recreational Craft during Regular Lockage

The lockage process of recreational vessels is recorded at the times of SOL (start of lockage) and EOL (end of lockage). There is additional time for each additional recreational boat being added into lockage process. As shown in Figure 16, the total lock processing time for a group of recreational vessels will be estimated as the original lock processing time plus the additional time for each additional vessel. For example, if 10 recreation vessels are locked as a group with 2 minutes extra time per boat, the total processing time is the processing time for the first recreation vessel (from processing time distribution for recreational craft) plus the additional time of 18 minutes (i.e. 2×9 for additional 9 boats).

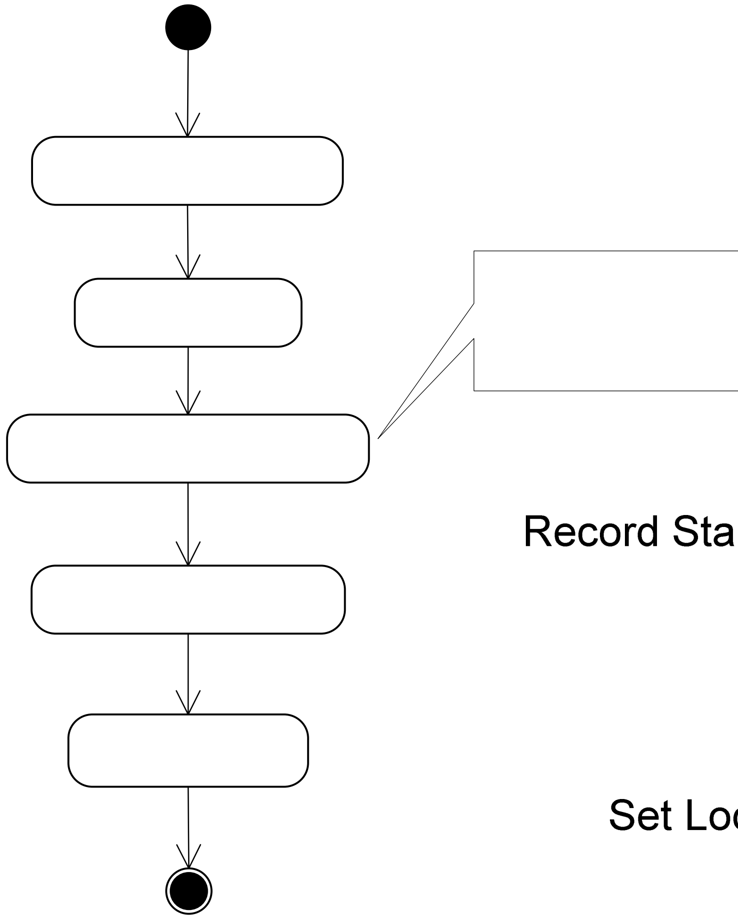


Figure 16 "Start of Lockage" Event for Recreational Vessels

Multi-Recreational Craft during Chamber Turn Back

As discussed in the previous section, one way to increase the lockage efficiency is locking through the recreation vessels during the chamber turnback between cuts of multi-cut lockage. That is, if a 2-cut tow is going downstream, the lock operator will allow upstream recreation craft to be served during the chamber turnback between the 1st and 2nd cuts. Therefore, if a recreational vessel is allowed in the chamber where the multi-cut lockage is in process, and also allowed during the chamber turnback (as indicated in column of “AllowedInTurnback” in Table 22), recreation vessels can be locked through between cuts.

Unlike the regular recreational lockage, the processing time for locking a recreational vessel during the chamber turnback is the chamber turnback time plus additional time for each recreation vessel served during the turnback. Information in tblChamberOpsLevel10, columns of “FillChamberTB”, “MultipleFillChamberTB”, “EmptyChamberTB”, and “MultipleEmptyChamberTB” (as shown in Table 24), is used to estimate the processing time for recreational vessels while in chamber turnback, rather than “ProcessingTime” used in regular recreational lockage.

Table 24 Processing Time for Recreational Vessels during Chamber Turnback

	ChamberID	VesselTypeID	LkgType	FillChamTB	MultipleFillChamTB	EmptyChamTB	MultipleEmptyChamTB
1	83	10	S	257	531	258	531
2	84	10	S	459	531	460	531

If there are multiple recreation vessels, the processing time will be the turnback time plus the additional time for each recreation vessel (as shown in Figure 17). For example, if 5 recreation vessels can be locked through during the chamber turnback and 2 minutes extra time per boat, the total processing time for this recreational lockage is the chamber turnback time (from chamber turnback time distribution) plus the additional time of 10 minutes (i.e. 2×5 for additional 5 boats).

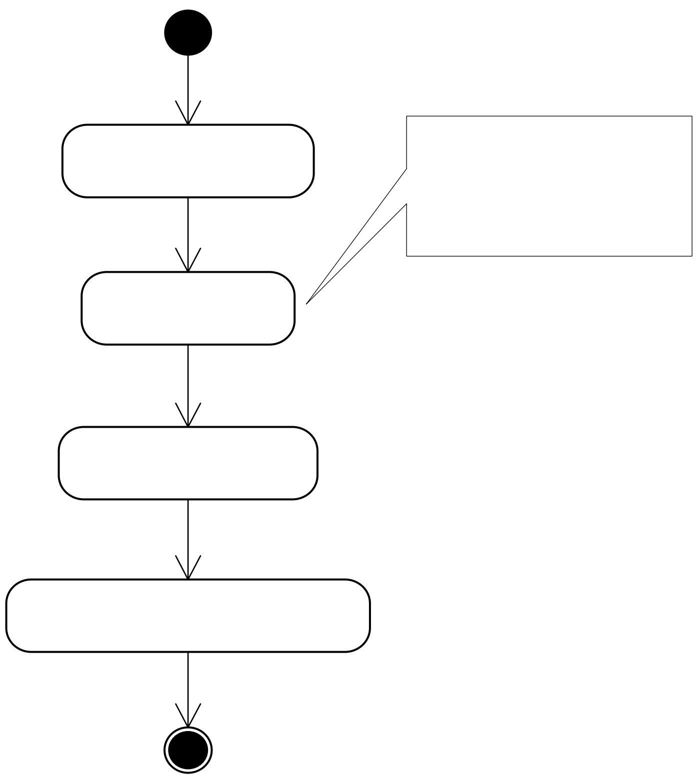


Figure 17 "Start of Chamber Turnback" Event

Lockage during Chamber Turn back

As discussed in the previous section, one way to increase the lockage efficiency is locking through the recreation vessels during the chamber turnback between cuts of multi-cut lockage. This kind of lockage operation could be extended to lock through the smaller vessels, such as recreational vessels and light boats, during the chamber turnback between cuts of multi-cut lockage, or between two regular lockages for two separate vessels. Two conditions are needed for having chamber turnback between vessels:

- A vessel makes its fly approach but water levels are different on two sides of pool

- A vessel finishes its turnback exit and makes its post-exit

For both conditions, vessels make their approach or exit as well as asking for chamber turnback. In the first condition, a chamber is turning back for the vessel which is making a fly approach. In the second condition, a chamber is turning back for the vessel which is making a turnback approach. At this moment, the user can specify if a specific vessel type is allowed in chamber turnback (as shown in Table 22). It is noted that if a specific vessel type is not allowed in a chamber, it is not allowed in chamber turnback either.

For those turnback lockages, there are detailed lockage components of approach, entry, chambering and exit. The lockage processing time is estimated with an overall chamber turnback time plus time required for each extra vessels. This estimation is similar to the one shown in Figure 17.

Lockage for Multiple Recreational Vessels

Locking multiple recreational vessels has been discussed in the previous section.

Lockage for Multiple Light Boats

Vessel and chamber dimensions are required to lock multiple light boats during chamber turnback. Since light boats are commercial vessel,this is actually a special case of multi-vessel lockage during chamber turnback, with buffer distance but no search limit in the queue. Therefore, similar operation logic (as shown in Figure 12) should apply in this situation.

Lockage for Mixed-Light Boats and Recreational Vessels

This situation would be similar to regular mixed-vessel lockage but occurring during the chamber turnback. That is, if the first selected vessel is recreational, other recreational vessels, no light boats, will be selected to make a recreational turnback lockage. If the first selected vessel is light boat, other light boats and recreational vessels can be selected to make a mixed-vessel turnback lockage. The operation logic should be similar to the one shown in Figure 15.

Interference

Some physical interference between vessels is observed at multi-chamber locks. Such lock interference actually compels the waiting vessel to wait while another vessel, using the other chamber, finishes an action, even though its intended chamber is ready for service. Based on the lock operators' definition, recreational craft and light boats cannot cause or are not affected by interference. Two kinds of interference are considered in current waterway operation: approach area interference and gate area interference. Both kinds of interference may occur between commercial tows, light boats, passenger and government vessels while a multi-chamber lockage is operated.

For simulation purposes, it is very important to consider the interference with the description of the location of a vessel within the internal geometry of a lock. Therefore, the definition of lock geometry and movement is necessary to determine when the approach area and gate area interferences occur (i.e., when approach and gate areas are clear or blocked). Figure 18 shows the internal geometry of a lock and the definitions of approach area and the gate area. It is noted that some of these are not physically exact (such as gate area) defined locations in the real world, but a logically operated step in the lockage operation.

- **Approach Point:** a designated location indicated by markers on the shore. A vessel arriving at the lock enters the lock reach at this point.
- **Gate Area Wait Point**: a location that represents the point at which the bow of the vessel waits to begin a turnback approach. The vessel will wait at this point until the lock is ready for entry.
- **Sill**: the point at which a lockage (or cut) entry starts.
- **Approach Area**: the spatial extent from the approach point to the gate area wait point in the same side.
- **Gate Area**: the spatial extent from the gate area wait point to the chamber sill location on the same side.

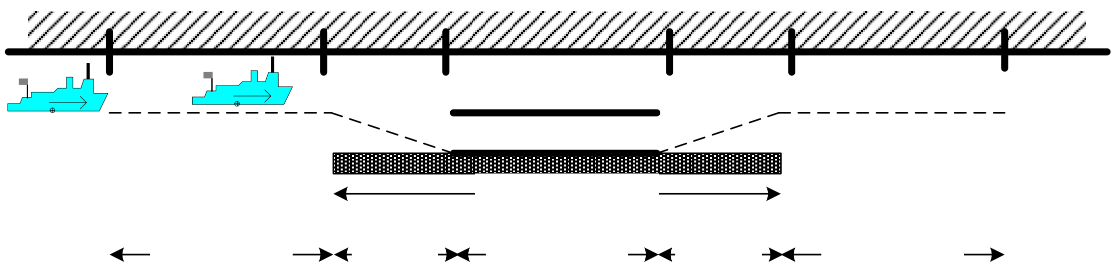


Figure 18 Lock Reach Internal Geometry

The logic required to model interference is developed during this Phase 3. The users need to specify interference parameters, especially for gate area interference, via database.

Approach Area Interference

Approach area interference considers lockage at the two-chamber locks as passing through a series including a "single-server" approach area, a "two-servers" chamber area, and another "single-server" approach area, as shown in Figure 19. When a vessel is on its exit in the approach area, another approaching vessel in the opposite direction cannot start its lockage even if the other chamber is idle. Similarly, when a vessel in on its approach to its targeted chamber, the vessel in the other chamber, heading opposite direction, cannot make its exit even though the chambering is finished. That is, when a tow is in the approach area, either (pre)approaching or (post)exiting a chamber, another tow can not occupy that approach area to (pre)approach or (post)exit the other chamber.

A similar situation seems to also occur at single-chamber locks since the approach area is “shared” by approaching and exiting vessels. Whenever a vessel makes its exchange exit, the vessel planning to make exchange approach should keep waiting at the approach point until the approach area is cleared by the exiting vessel. Although there is possible waiting for using the approach area, the term “interference” is not considered at single-chamber locks, but only at multi-chambers locks. Due to the interference, some vessels cannot make their move to the available chamber.

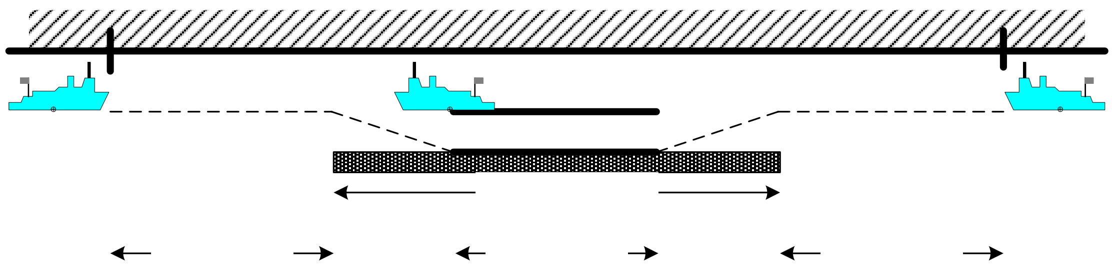
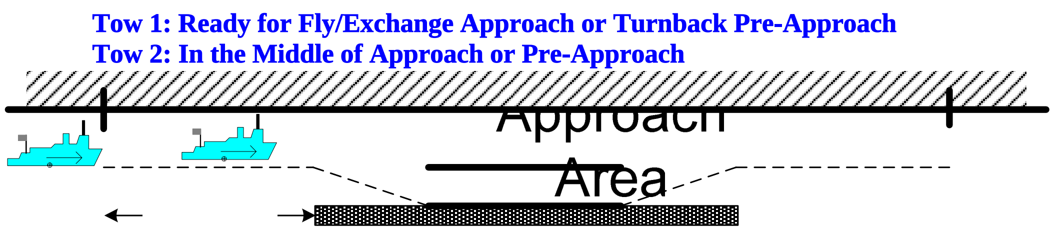


Figure 19 Approach Area Interference

In order to model the approach area interference, detailed lockage components are associated with the definitions of upstream or downstream approach area interference. The following conditions demonstrate the details of approach area interference.

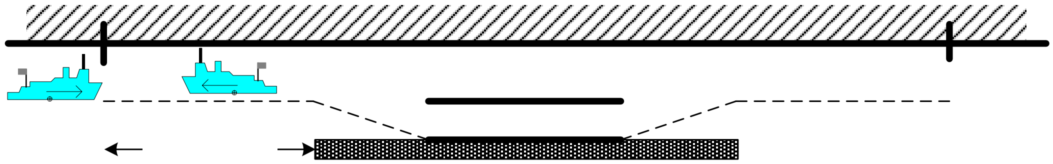
- If Tow 1 is selected as the next vessel served by a chamber and it is ready for the fly/exchange approach or turnback pre-approach, it may be stuck at the approach point due to the approach area interference caused by:

  (a) Tow 2, going the same direction as Tow 1, is in the middle of its fly/exchange approach or turnback pre-approach (Figure 20 (a));
  (b) Tow2, going in the opposite direction from Tow 1, is in the middle of its fly/exchange exit or turnback post-exit (Figure 20 (b)).



(a)

Tow 1: Ready for Fly/Exchange Approach or Turnback Pre-Approach
Tow 2: In the Middle of Fly/Exchange Exit or Turnback Post-Exit



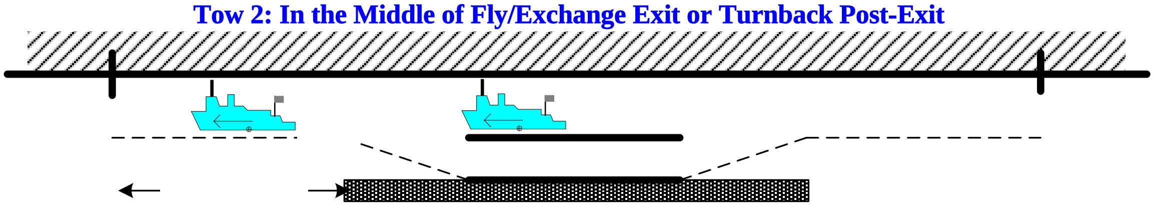
(b)

- If Tow 1 has finished its chambering and is ready for the fly/exchange exit, it may hold its exit due to the approach area interference caused by:
  (c) Tow 2, going the same direction as Tow 1, is in the middle of its fly/exchange exit or turnback post-exit (Figure 20 (c));
  (d) Tow 2, going the opposite direction as Tow 1, is in the middle of its fly/exchange approach or turnback pre-approach (Figure 20 (d)).

Tow1 Tow2

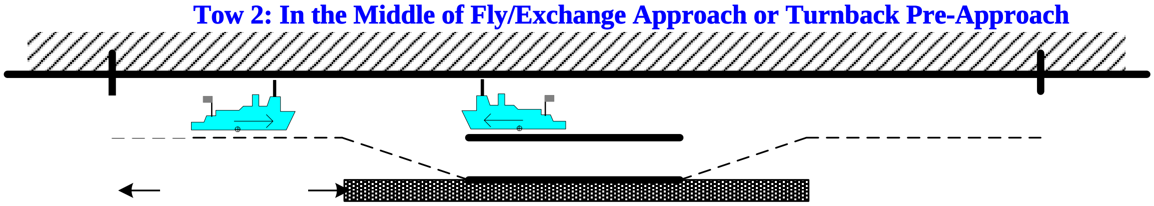
Approach
Area

Tow 1: Ready for Fly/Exchange Exit
Tow 2: In the Middle of Fly/Exchange Exit or Turnback Post-Exit



(c)

Tow 1: Ready for Fly/Exchange Exit
Tow 2: In the Middle of Fly/Exchange Approach or Turnback Pre-Approach



(d)

- If Tow 1 has finished its turnback exit and is ready for the turnback post-exit, it may hold its post-exit due to the approach area interference caused by:

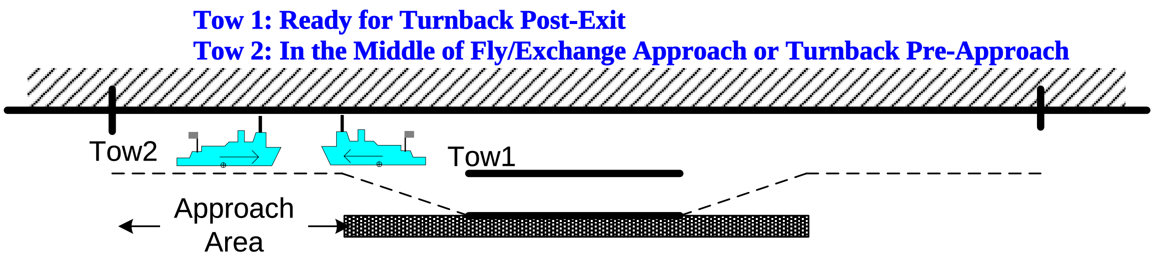
  (e) Tow 2, going the same direction as Tow 1, is in the middle of its fly/exchange exit or turnback post-exit (Figure 20 (e));
  (f) Tow 2, going in the opposite direction from Tow 1, is in the middle of its fly/exchange approach or turnback pre-approach (Figure 20 (f)).

Tow 1: Ready for Turnback Post-Exit
Tow 2: In the Middle of Fly/Exchange Exit or Turnback Post-Exit

Tow2

Approach
Area

(e)



(f)

Figure 20 Conditions of Approach Area Interferences

Gate Area Interference

Gate area interference occurs while vessels are in the entry process and arriving at the gates, or while they are assembled or disassembled into cuts (as shown in Figure 21). If the breaking cuts are waiting outside of gate area or arriving vessels are entering the gate, the finishing vessel in another chamber cannot start exiting unless the remaining space in gate area is large enough for both vessels to pass through.

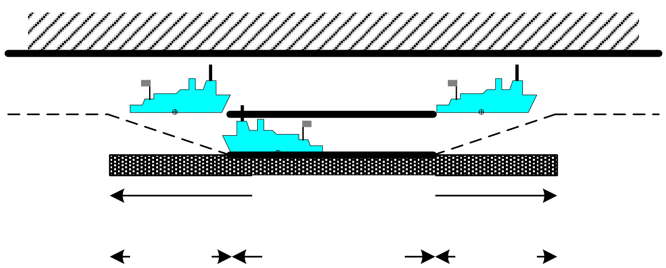


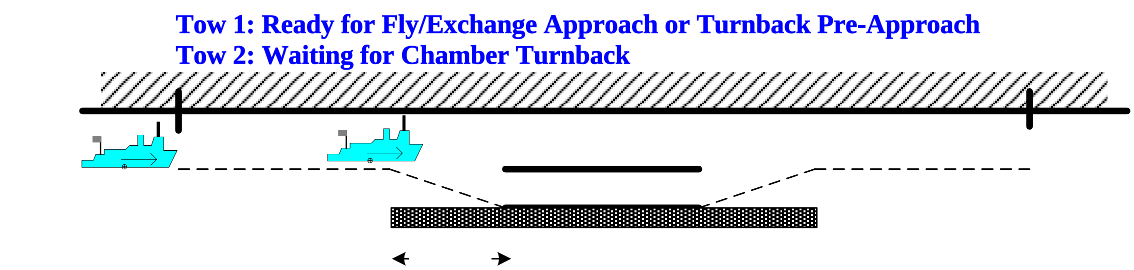
Figure 21 Gate Area Interference

Gate area interference may occur when a tow, or part of a tow, is waiting near the gates of a lock chamber. Gate area interference can prevent another tow from (pre)approaching the other chamber, extracting a cut from the other chamber or exiting the other chamber. Whether gate area interference occurs depends upon the configuration of the lock, upstream and downstream critical lengths for the lock, and the length of the waiting tow.

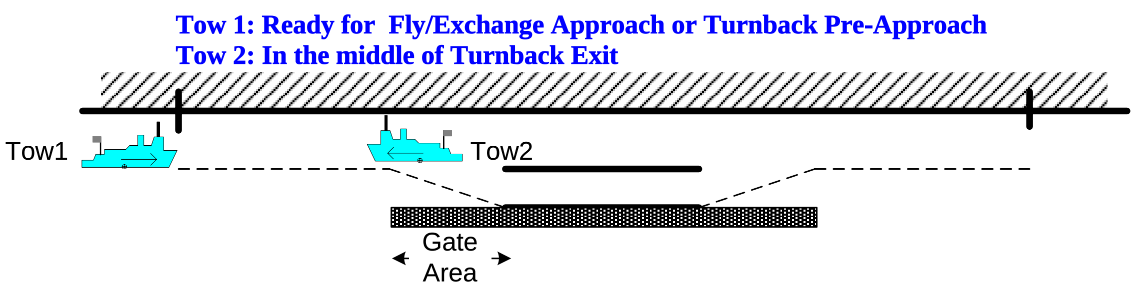
Similarly, in order to model the gate area interference, detailed lockage components are associated with the definitions of upstream or downstream gate area interference. The following conditions demonstrate gate area interference:

- If Tow 1 is ready for the fly/exchange approach or turnback pre-approach, it may be stuck at the approach point due to the gate area interference caused by:

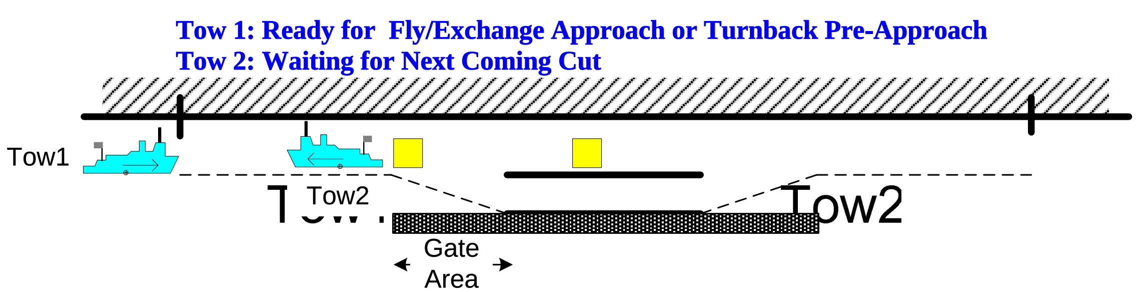
  (a) Tow 2, going the same direction as Tow 1, is waiting for chamber turnback at the gate area wait point with an overall vessel length longer than the critical length. Tow 2 can be a single-cut or a multi-cut vessel. (Figure 22 (a))
  (b) Tow 2, going in the opposite direction from Tow 1, is doing a turnback exit with an overall vessel length longer than the critical length. (Figure 22 (b))
  (c) Tow 2, a multi-cut vessel going the opposite direction as Tow 1, is waiting for next cut at the gate area wait point and its current length exceeds the critical length. (Figure 22 (c))



(a)



(b)



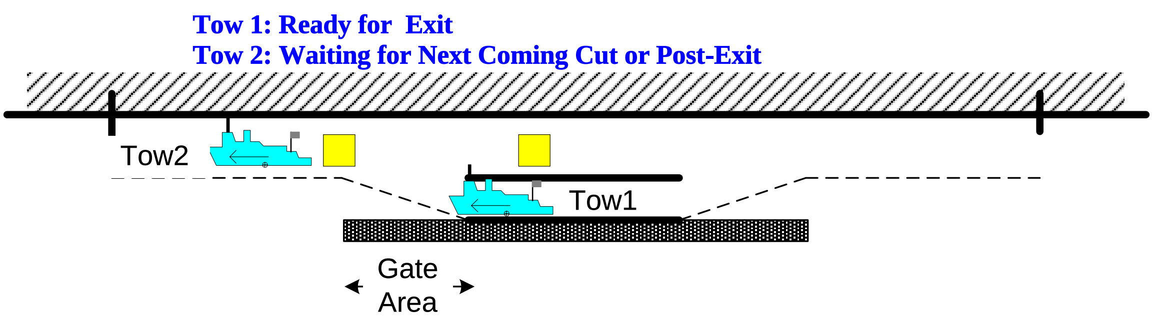
(c)

- If Tow 1 is ready for fly/exchange/turnback exit, it may hold (i.e. delay) its exit due to the gate area interference caused by:

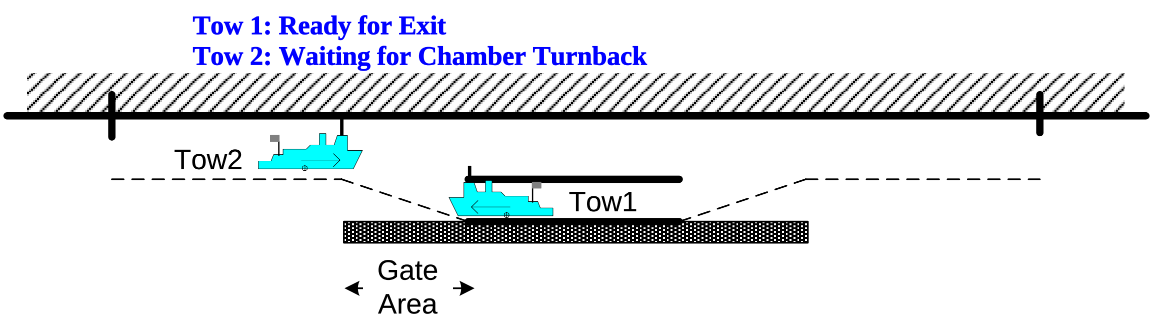
  (d) Tow 2, going the same direction as Tow 1, is sitting at the gate area wait point and exceeds the critical length. Tow 2 may be waiting to pursue its post-exit when the approach area is clear, or waiting for the next cut that still in process. (Figure 22 (d)) Similarly, Tow 2 is sitting at the gate area with a length less than the critical length and Tow 1 is ready for exit, Tow 1 can proceed its exit and may cause interference for the last cut of Tow 2 when the last cut of Tow 2 is ready for exit.

(e) Tow 2, going in the opposite direction from Tow 1, is sitting at the gate area wait point and exceeds the critical length. Tow 2 can be waiting for the chamber turnback, or waiting for processing the next cut (Figure 22 (e))

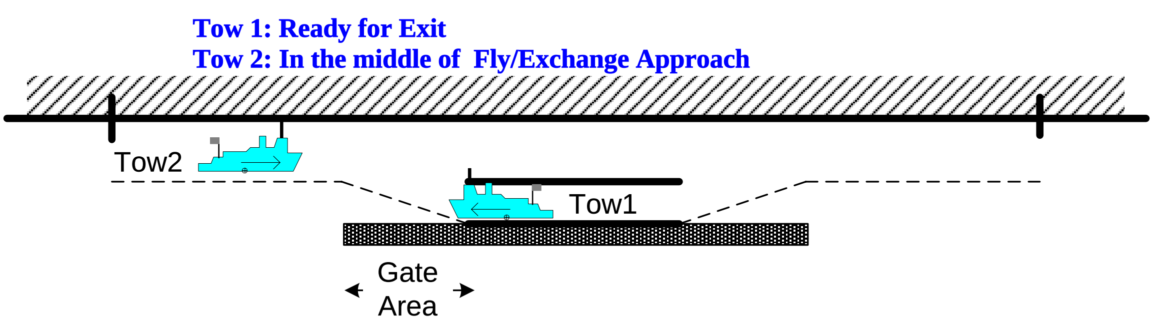
(f) Tow 2, going in the opposite direction from Tow 1, is making a fly/exchange approach. If the exit of Tow 1 will cause gate area interference to Tow 2, Tow 1 will hold its exit to avoid gate area interference (Figure 22 (f)).



(d)



(e)



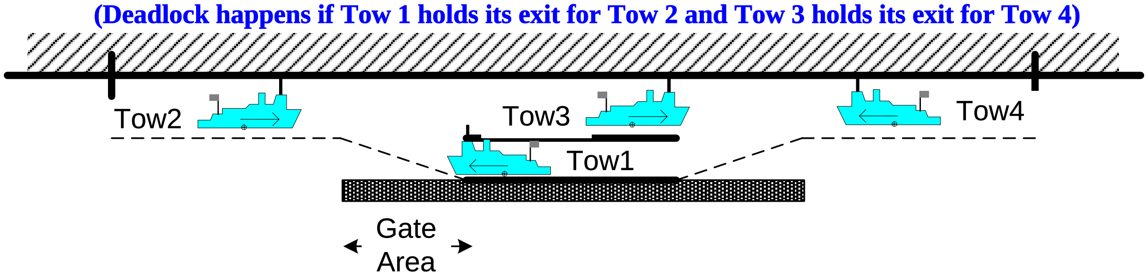
(f)

Figure 22 Conditions of Gate Area Interference

Although the passing rules for the vessels in the lockage process are clearly addressed in previous cases if gate area interference occurs, there are still some situations in which the "deadlock' can possibly occur when tows block each other (hold their actions) by considering the interference.

- In Figure 22 (f), Tow 1 is making a fly/exchange exit and it will hold its exit to avoid gate area interference to Tow 2. However, as shown in Figure 23 (a), if Tow 1 is making a turnback exit as well as Tow 3 is, both of them will hold their exit to avoid gate area interference for Tow 2 and Tow 4, respectivly. In this case, those lockages will never be ended and four tows are "stuck" at locks and chambers. Thus in this case, no gate area interference will be checked if Tow 2 is making a turnback pre-approach. That is, Tow 1 and Tow 3 should start their exit without considering the gate area interference.

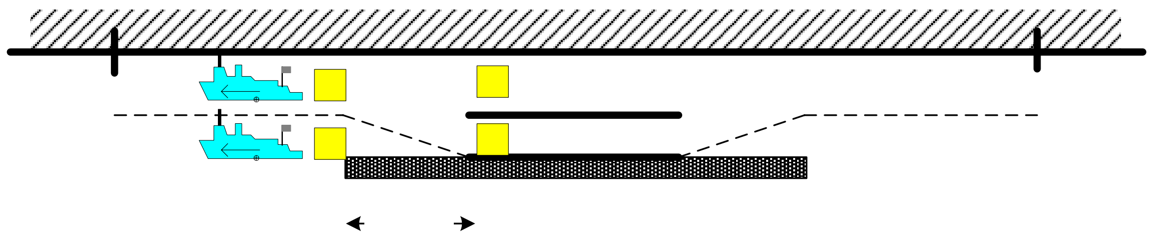
Tow 1: Ready for Exit
Tow 2: In the middle of Turnback pre-approach
Tow 3: Ready for Exit
Tow 4: In the middle of Turnback pre-approach
(Deadlock happens if Tow 1 holds its exit for Tow 2 and Tow 3 holds its exit for Tow 4)



(a)

- In Figure 22 (d), Tow 1, a single-cut vessel, holds its exit due to gate area interference caused by Tow 2. Or the last cut of Tow 2 holds its exit to avoid gate area interference for Tow 1. It should be noted that the gate area interference does not prevent the operation of cut extraction. That is, the 1st cut or middle cuts can be extracted without regard to the gate area interference after completing the chambering. The last cut, which proceeds the exit rather than cut extraction in DLM model, would hold its exit if there is gate area interference (as shown in the previous figures). However, if two multi-cut tows, traveling in the same direction, make their cut extraction without considering gate area interference, both tows might sit at the gate area with overall length exceeding the critical length (as shown in Figure 23 (b)). Since their last cuts will hold their exit after checking the gate area interference, those lockages will never be ended and two tows and their last cuts are "stuck" at locks and chambers. Thus in this case, both cuts should proceed with their exit without considering the gate area interference.

Tow 1: Wait for the last coming cut for exit
Tow 2: Wait for the last coming cut for exit
(Deadlock happens if the last cuts of Tow 1 and Tow 2 hold their exit due to interference)



(b)

Figure 23 Deadlock in Gate Area Interference

Operation Logic

Figure 24 shows the components used in modeling interference in DLM. In the detailed lock model, there are only two approach areas, upstream and downstream, shared by multiple chambers. Each chamber has its own two gate areas, upstream and downstream. If a vessel travels upstream, it will pass GoingUpAA, GoingUpGA, Chamber, GoingDnGA and GoingDnAA; and vice versa for a vessel traveling downstream.

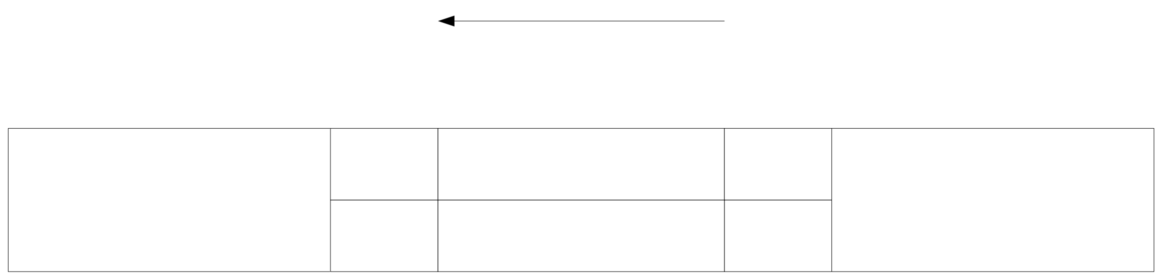


Figure 24 Definition f Gate Area Interference

As discussed previously approach area interference is defined as a "yes/no" condition. It occurs simply if there is a vessel occupying the approach area for processing its approach or exit. However, gate area interference is defined with a critical length which might prevent other vessel's approach or exit. Therefore, a vessel traveling upstream will check the interference as follows, and vice versa.

1. check the upstream approach area interference
2. if there is no approach area interference, check the critical length of upstream gate area interference while processing its approach.
3. after chambering, check the critical length of downstream gate area interference while processing its exit
4. if there is no gate area interference, check the downstream approach area interference

Data Inputs

There are no inputs required to specify the approach area interference. It is directly modeled in the logic with a "flag" indicating if approach areas are occupied by vessels. However, inputs for gate area interference are necessary. It could be varied by the direction of river flow and the lockage operation of vessels.

In the chamber table, four columns of gate area interference (as shown in Table 25) are specified based on length, direction and lockage components (approach or exit). If the critical length of upstream gate area interference for upstream approach area is specified as 1200 feet, it means that if a vessel with more than 1200 feet sitting in front of gate is likely to "block" the vessel which is traveling toward upstream and ready for starting its approach. Usually, the critical lengths of gate area interference for the exiting vessels are shorter than those for the approaching vessels, based on safety and maneuver concerns

Table 25 Definition of Gate Area Interference

	ChamberID	GAInterferenceUpApp	GAInterferenceDownApp	GAInterferenceUpExit	GAInterferenceDownExit
1	83	1200	1200	600	600
2	84	1200	1200	600	600

Model Interference

From the above analysis, interference is only considered when vessels perform approach or exit in their lockage process. Among the events or processes modeled in DLM, approach area interference is considered in the event of arrival, and process of removing vessel from queue. Gate area interference is considered in the events of end of chambering, and end of turnback exit. It will be necessary to check approach and gate area in the following lockage process of a vessel (as shown in Table 26).

Table 26 The Activities required to check Approach/Gate Area Interferences

The Vessel is Ready For Start	Check Approach Area Interference	Check Gate Area Interference
Fly Approach	√	√
Exchange Approach	√	√
Turnback Pre-Approch	√	√
Turnback Approch	×	×
Cut Approach	×	×
Fly Exit	√	√
Exchange Exit	√	√
Turnback Exit (vs. Fly/Exchange Approach)	×	√
Cut Extraction (vs. Fly/Exchange Approach)	×	√
Turnback Exit (vs. Turnback Pre-Approach)	×	×
Cut Extraction (vs. Turnback Pre-Approach)	×	×
Turnback Post-Exit	√	×

- For Fly/Exchange Approach/Exit and turnback Pre-approach, both gate and approach area interferences should be checked. The checking logic is shown in Figure 25 and Figure 26)

- For turnback exits and cut extractions, we do not need to check for approach area interference because the vessels are only moving out of the chamber. We would check if the activities should hold due to gate area interference or whether they will cause future gate area interference to a vessel that is currently making a fly or exchange approach to the other chamber. However, we ignore the possible gate area interference caused by turnback exits and cut extractions if there is a vessel making pre-approach to the other chamber. The checking logic is shown in Figure 27.
- For turnback post-exits, we only check the approach area to see if it allows the post exit. The checking logic is shown in Figure 28.

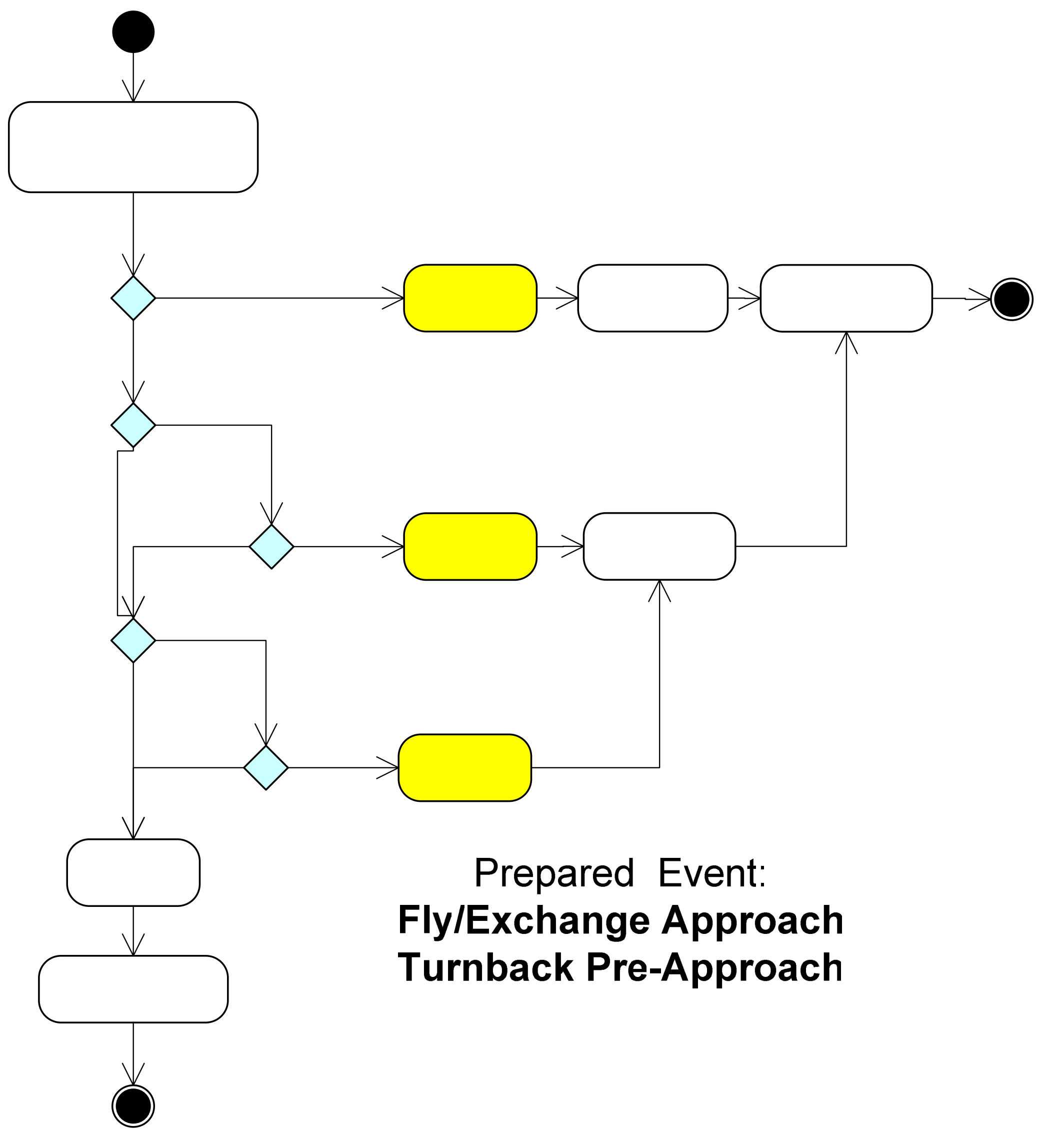


Figure 25 Interference Logic for Fly/Exchange Approach or Turnback Pre-Approach

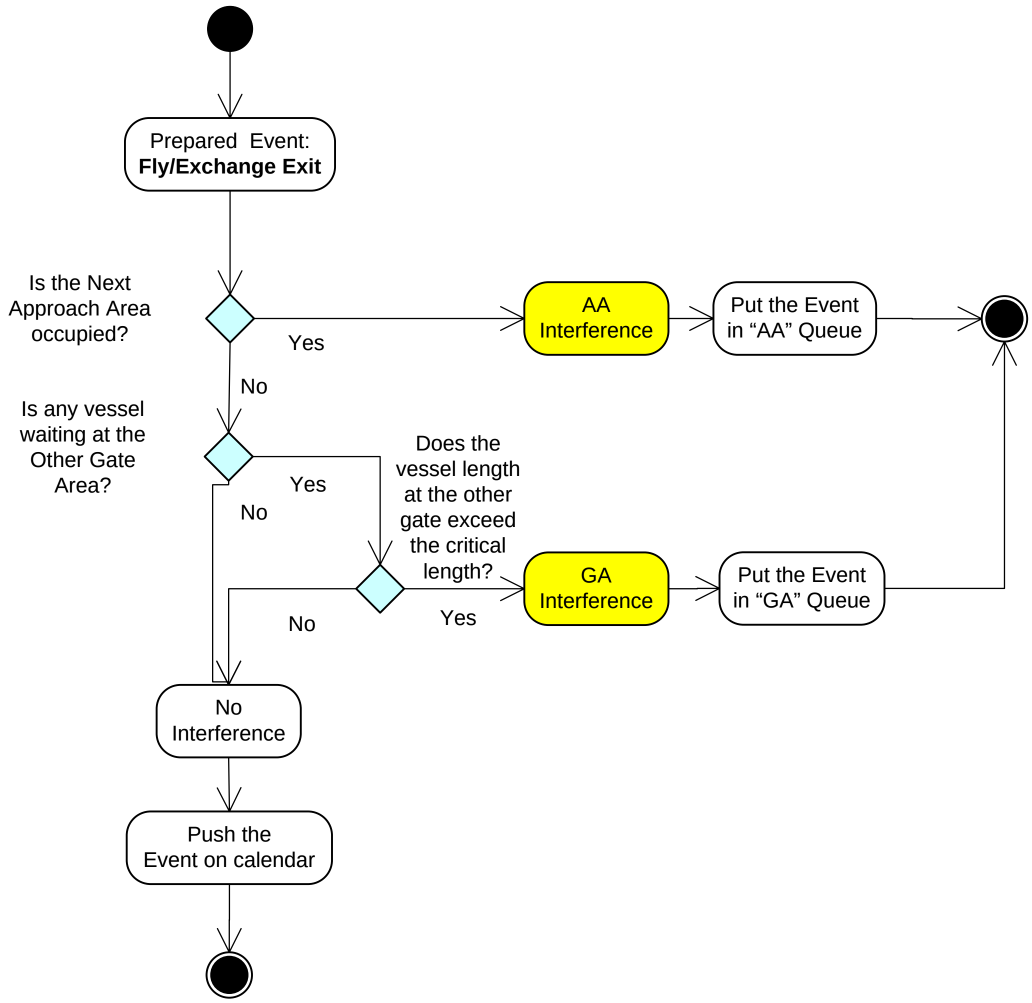


Figure 26 Interference Logic for Fly/Exchange Exit

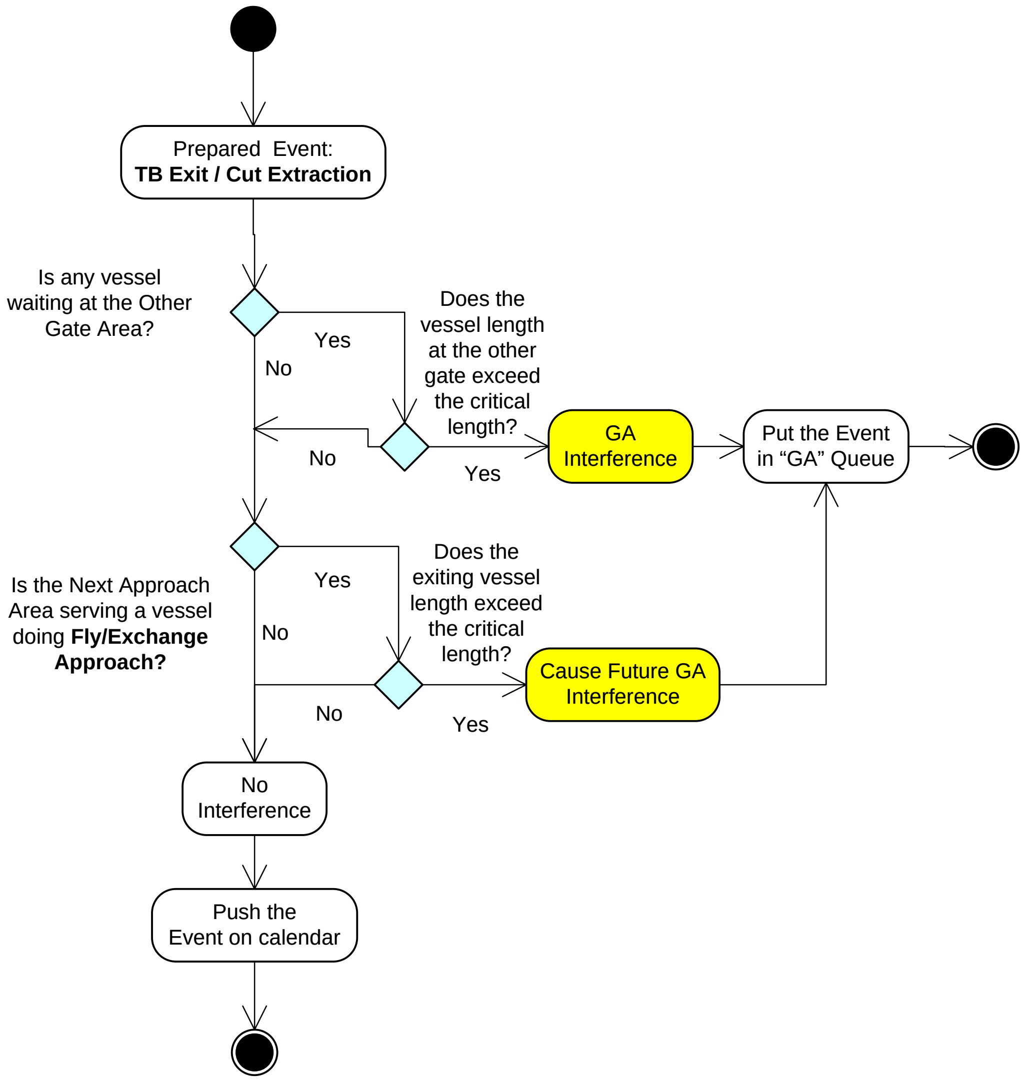


Figure 27 Interference Logic for Turnback Exit or Cut Extraction

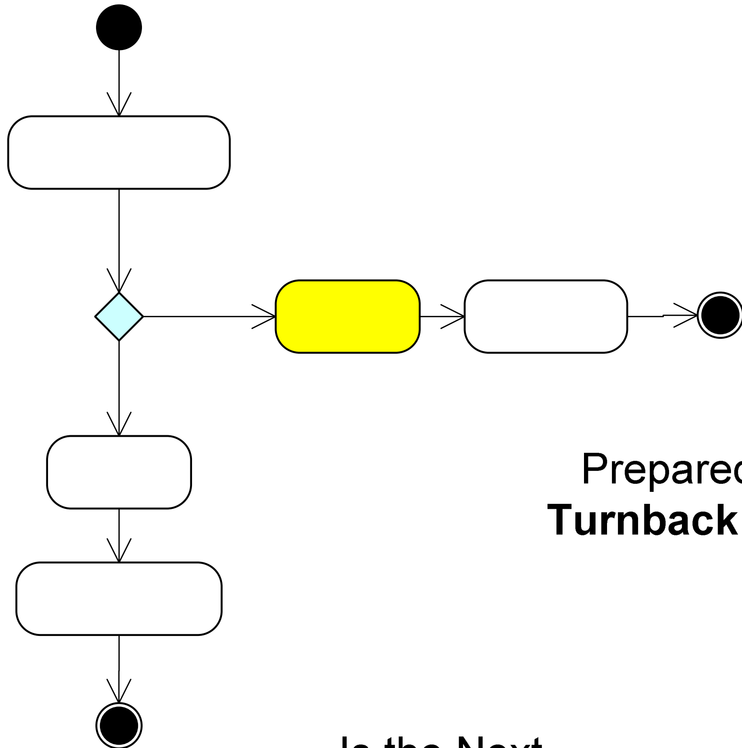


Figure 28 Interference Logic for Turnback Post-Exit

Model Test

Currently, DLM is designed to run individually for a single-lock system, as well as serve as a module which will be integrated into network simulation model, BasinSym. In order to check all the designed features in DLM, a model test is performed to ensure the correct logic and expected test results.

Study Lock

The Marmet Lock on the Kanawha River, a tributary of the Ohio River, is selected for the test purpose. It is a two-chamber lock located between the London upstream lock, and the Winfield downstream lock. From the network definition of NaSS, a single-lock system is designed as a lock reach, which differs from a regular reach, with two nodes at the ends.

Input Data

For integration purposes, DLM and NaSS share the same data structure. Therefore, an SQL database, "BasinSym", which is used by NaSS, is used for testing the DLM with specific information for Marmet.

Lock Information

The current information about the Marmet Lock is shown on Table 27. The IDs used in network configuration are defined in NaSS.

Table 27 2007 Lock Information at Marmet

Lock Characterstics		
Lock ID		54
Reach ID		212
Upstream Node ID		213
Downstream Node ID		214
Number of Chamber		2
Chamber ID	Main	83
	Aux	84
Chamber Dimension	Main	360×56
	Aux	360×56

Vessel Information

The current shipment list for the Marmet Lock, provided by DAPP, has one year of shipment data for year 2007 (as shown in Table 28). There are 6653 vessels in total with 6601 commercial trips and 52 recreational trips in year 2007 data. In the given shipment list no high priority vessels, such as government vessels and passenger vessels, are recorded at the Marmet Lock in the year 2007.

Table 28 2007 Vessel Information at Marmet

Vessel Type	Total	Upstream	Downstream
Tows (Commercial Vessels)	6601	3300	3301
Recreational Vessels	52	29	23
High Priority Vessels	0	0	0
Other Vessels	0	0	0

Operation Information

The current policy adopted at the Marmet lock is FIFO (first come first serve) for both chambers. In the Ohio River, since most of the locks are two-chamber locks, recreational craft are not usually allowed in the main chamber and are forced to wait 3 (up to 3) commercial lockages before starting their recreational lockage. Detailed lockage information is shown in Table 29.

Table 29 2007 Operation Information at Marmet

Lock Operations	Policies
Control Policy	FIFO (for both chambers)
Recreational Craft	Not allowed in main chamber Wait for 3 commercial lockages
Gate Area Interference	1200 ft (Approach) / 600 ft (Exit)

Cut Limit	10 (for both chambers)	
Help Equipment	No (for both chambers)	
Assistance	No (for both chambers)	
Lockage	Navigable Pass	No
	Multi-Vessel Lockage (at most 2 vessels)	Yes
	Mixed-Vessel Lockage (No limit)	Yes
	Multi-Rec Lockage (one Rec per 100 feet)	Yes
	Chamber Turnback Lockage	Yes

Closure Information

From the historical data, there are a total of 72 scheduled outages in the year 2007 (as shown in Table 30). Those outage periods vary and are not recurring ones. Detailed outages are shown in the SQL database, *tblScheduledOutage*.

Table 30 2007 Closure Information at Marmet

Chamber	Total	Recursive	<= 1 hours	> 1 & < 3	>= 3 hours
Main	34	No	16	12	6
Aux	38	No	17	16	5

Processing Time Distributions

Processing time distributions for detailed lockage components and various vessel types are provided by DAPP, shown in *tblChamberOpsLevel10* in SQL database. The additional time for multi-vessel lockage is assumed in this test.

Test Results

Vessel Log File

In order to assure the correct logic flow in DLM, details in the lockage components for any single vessel are recorded. With this output, each single vessel can be traced in the program. It also helps to check the program logic during the development. The following sessions are some examples of lockage output with detailed lockage process upon various time points, step by step.

Single-Cut Tow

Single-cut tows are smaller commercial vessels which can carry zero barges, such as a light boat, or few barges as long as they can fit into the chamber. Each single-cut tow in DLM passes through approach (fly/exchange/turnbak), entry, chambering, and exit (fly/exchange/turnback).

- Single-Cut Tow with Fly Approach (as shown in Table 31)
- Single-Cut Tow with Exchange Approach (as shown in Table 32)
- Single-Cut Tow with Turnback Approach (as shown in Table 33)

Table 31 Vessel Log of Single-Cut Tow with Fly Approach

(a) Fly Exit

	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
47	9.5833	PROCREACH	ArriveLock	54	83	69	T	11	S	Up	1	
48	9.5833	LOCKOP	StartFlyApp	54	83	69	T	11	S	Up	1	
49	9.6833	LOCKOP	EndFlyApp	54	83	69	T	11	S	Up	1	
50	9.6833	LOCKOP	StartEntry	54	83	69	T	11	S	Up	1	1
51	9.75	LOCKOP	EndEntry	54	83	69	T	11	S	Up	1	1
52	9.75	LOCKOP	StartChambering	54	83	69	T	11	S	Up	1	1
53	9.8667	LOCKOP	EndChambering	54	83	69	T	11	S	Up	1	1
54	9.8667	LOCKOP	StartFlyExit	54	83	69	T	11	S	Up	1	1
55	9.9833	LOCKOP	EndFlyExit	54	83	69	T	11	S	Up	1	
56	9.9833	LEAVEREACH	LeaveLock	54		69						

(b) Exchange Exit

	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
10421	528.3333	PROCREACH	ArriveLock	54	83	5154	T	11	S	Up	1	
10422	528.3333	LOCKOP	StartChamberTB	54	83	5154	T	11	S	Up	1	1
10423	528.3333	LOCKOP	StartFlyApp	54	83	5154	T	11	S	Up	1	
10428	528.5	LOCKOP	EndChamberTB	54	83	5154	T	11	S	Up	1	
10431	528.55	LOCKOP	EndFlyApp	54	83	5154	T	11	S	Up	1	
10432	528.55	LOCKOP	StartEntry	54	83	5154	T	11	S	Up	1	1
10435	528.6333	LOCKOP	EndEntry	54	83	5154	T	11	S	Up	1	1
10436	528.6333	LOCKOP	StartChambering	54	83	5154	T	11	S	Up	1	1
10438	528.7333	LOCKOP	EndChambering	54	83	5154	T	11	S	Up	1	1
10439	528.7333	LOCKOP	StartExchExit	54	83	5154	T	11	S	Up	1	1
10442	528.9167	LOCKOP	EndExchExit	54	83	5154	T	11	S	Up	1	
10443	528.9167	LEAVEREACH	LeaveLock	54		5154						

(c) Turnback Exit

	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
794	73.0833	PROCREACH	ArriveLock	54	84	72	T	11	S	Dn	1	
795	73.0833	LOCKOP	StartChamberTB	54	84	72	T	11	S	Dn	1	1
796	73.0833	LOCKOP	StartFlyApp	54	84	72	T	11	S	Dn	1	
799	73.1276	LOCKOP	EndFlyApp	54	84	72	T	11	S	Dn	1	
802	73.2167	LOCKOP	EndChamberTB	54	84	72	T	11	S	Dn	1	
803	73.2167	LOCKOP	StartEntry	54	84	72	T	11	S	Dn	1	1
804	73.35	LOCKOP	EndEntry	54	84	72	T	11	S	Dn	1	1
805	73.35	LOCKOP	StartChambering	54	84	72	T	11	S	Dn	1	1
813	73.6	LOCKOP	EndChambering	54	84	72	T	11	S	Dn	1	1
815	73.6	LOCKOP	StartTBExit	54	84	72	T	11	S	Dn	1	1
821	73.85	LOCKOP	EndTBExit	54	84	72	T	11	S	Dn	1	
822	73.85	LOCKOP	StartChamberTB	54	84	72	T	11	S	Dn	1	1
823	73.85	LOCKOP	StartTBPostExit	54	84	72	T	11	S	Dn	1	
824	73.9	LOCKOP	EndTBPostExit	54	84	72	T	11	S	Dn	1	
825	73.9	LEAVEREACH	LeaveLock	54		72						
826	73.9333	LOCKOP	EndChamberTB	54	84	72						

Table 32 Vessel Log of Single-Cut Tow with Exchange Approach

(a) Fly Exit

	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
4991	278.9167	PROCREACH	ArriveLock	54		9	T	11	S	Dn	1	
4994	279.0084	LOCKOP	StartExchApp	54	83	9	T	11	S	Dn	1	
4999	279.2359	LOCKOP	EndExchApp	54	83	9	T	11	S	Dn	1	
5000	279.2359	LOCKOP	StartEntry	54	83	9	T	11	S	Dn	1	1
5004	279.3025	LOCKOP	EndEntry	54	83	9	T	11	S	Dn	1	1
5005	279.3025	LOCKOP	StartChambering	54	83	9	T	11	S	Dn	1	1
5006	279.4192	LOCKOP	EndChambering	54	83	9	T	11	S	Dn	1	1
5009	279.5782	LOCKOP	StartFlyExit	54	83	9	T	11	S	Dn	1	1
5010	279.6115	LOCKOP	EndFlyExit	54	83	9	T	11	S	Dn	1	
5011	279.6115	LEAVEREACH	LeaveLock	54		9						

(b) Exchange Exit

1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
17118	833.9167	PROCREACH	ArriveLock	54		5166	T	11	S	Up	1	
17128	834.1135	LOCKOP	StartExchApp	54	84	5166	T	11	S	Up	1	
17131	834.1969	LOCKOP	EndExchApp	54	84	5166	T	11	S	Up	1	
17132	834.1969	LOCKOP	StartEntry	54	84	5166	T	11	S	Up	1	1
17134	834.3302	LOCKOP	EndEntry	54	84	5166	T	11	S	Up	1	1
17135	834.3302	LOCKOP	StartChambering	54	84	5166	T	11	S	Up	1	1
17140	834.5635	LOCKOP	EndChambering	54	84	5166	T	11	S	Up	1	1
17141	834.5635	LOCKOP	StartExchExit	54	84	5166	T	11	S	Up	1	1
17142	834.5969	LOCKOP	EndExchExit	54	84	5166	T	11	S	Up	1	
17143	834.5969	LEAVEREACH	LeaveLock	54		5166						

(c) Turnback Exit

1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
20543	1000.0833	PROCREACH	ArriveLock	54		659	T	11	S	Up	1	
20560	1000.4504	LOCKOP	StartExchApp	54	84	659	T	11	S	Up	1	
20561	1000.5837	LOCKOP	EndExchApp	54	84	659	T	11	S	Up	1	
20562	1000.5837	LOCKOP	StartEntry	54	84	659	T	11	S	Up	1	1
20563	1000.7004	LOCKOP	EndEntry	54	84	659	T	11	S	Up	1	1
20564	1000.7004	LOCKOP	StartChambering	54	84	659	T	11	S	Up	1	1
20567	1000.9228	LOCKOP	EndChambering	54	84	659	T	11	S	Up	1	1
20568	1000.9228	LOCKOP	StartTBExit	54	84	659	T	11	S	Up	1	1
20571	1001.1061	LOCKOP	EndTBExit	54	84	659	T	11	S	Up	1	
20572	1001.1061	LOCKOP	StartChamberTB	54	84	659	T	11	S	Up	1	1
20573	1001.1061	LOCKOP	StartTBPostExit	54	84	659	T	11	S	Up	1	
20574	1001.1228	LOCKOP	EndChamberTB	54	84	659	T	11	S	Up	1	
20576	1001.1311	LOCKOP	EndTBPostExit	54	84	659	T	11	S	Up	1	
20577	1001.1311	LEAVEREACH	LeaveLock	54		659						

Table 33 Vessel Log of Single-Cut Tow with Turnback Approach

(a) Fly Exit

1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
33755	1568.5	PROCREACH	ArriveLock	54		44	T	11	S	Up	1	
33778	1569.3568	LOCKOP	StartTBPreApp	54	83	44	T	11	S	Up	1	
33792	1570.0035	LOCKOP	EndTBPreApp	54	83	44	T	11	S	Up	1	
33793	1570.0035	LOCKOP	StartTBApp	54	83	44	T	11	S	Up	1	
33795	1570.0202	LOCKOP	EndTBApp	54	83	44	T	11	S	Up	1	
33796	1570.0202	LOCKOP	StartEntry	54	83	44	T	11	S	Up	1	1
33798	1570.1035	LOCKOP	EndEntry	54	83	44	T	11	S	Up	1	1
33799	1570.1035	LOCKOP	StartChambering	54	83	44	T	11	S	Up	1	1
33800	1570.1868	LOCKOP	EndChambering	54	83	44	T	11	S	Up	1	1
33801	1570.1868	LOCKOP	StartFlyExit	54	83	44	T	11	S	Up	1	1
33802	1570.2535	LOCKOP	EndFlyExit	54	83	44	T	11	S	Up	1	
33803	1570.2535	LEAVEREACH	LeaveLock	54		44						

(b) Exchange Exit

1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
6381	359.3333	PROCREACH	ArriveLock	54		5142	T	11	S	Up	1	
6424	360.5348	LOCKOP	StartTBPreApp	54	83	5142	T	11	S	Up	1	
6429	360.6129	LOCKOP	EndTBPreApp	54	83	5142	T	11	S	Up	1	
6447	361.0348	LOCKOP	StartTBApp	54	83	5142	T	11	S	Up	1	
6448	361.0681	LOCKOP	EndTBApp	54	83	5142	T	11	S	Up	1	
6449	361.0681	LOCKOP	StartEntry	54	83	5142	T	11	S	Up	1	1
6450	361.1014	LOCKOP	EndEntry	54	83	5142	T	11	S	Up	1	1
6451	361.1014	LOCKOP	StartChambering	54	83	5142	T	11	S	Up	1	1
6454	361.2014	LOCKOP	EndChambering	54	83	5142	T	11	S	Up	1	1
6455	361.2014	LOCKOP	StartExchExit	54	83	5142	T	11	S	Up	1	1
6458	361.2848	LOCKOP	EndExchExit	54	83	5142	T	11	S	Up	1	

(c) Turnback Exit

1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
34891	1607.75	PROCREACH	ArriveLock	54		3134	T	11	S	Up	1	
34953	1609.5333	LOCKOP	StartTBPreApp	54	83	3134	T	11	S	Up	1	
34956	1609.6492	LOCKOP	EndTBPreApp	54	83	3134	T	11	S	Up	1	
34967	1609.7721	LOCKOP	StartTBApp	54	83	3134	T	11	S	Up	1	
34968	1609.7888	LOCKOP	EndTBApp	54	83	3134	T	11	S	Up	1	
34969	1609.7888	LOCKOP	StartEntry	54	83	3134	T	11	S	Up	1	1
34970	1609.8554	LOCKOP	EndEntry	54	83	3134	T	11	S	Up	1	1
34971	1609.8554	LOCKOP	StartChambering	54	83	3134	T	11	S	Up	1	1
34975	1609.9721	LOCKOP	EndChambering	54	83	3134	T	11	S	Up	1	1
34976	1609.9721	LOCKOP	StartTBExit	54	83	3134	T	11	S	Up	1	1
34977	1610.0554	LOCKOP	EndTBExit	54	83	3134	T	11	S	Up	1	
34978	1610.0554	LOCKOP	StartChamberTB	54	83	3134	T	11	S	Up	1	1
34979	1610.0554	LOCKOP	StartTBPostExit	54	83	3134	T	11	S	Up	1	
34980	1610.1049	LOCKOP	EndTBPostExit	54	83	3134	T	11	S	Up	1	
34981	1610.1049	LEAVEREACH	LeaveLock	54		3134						
34984	1610.2221	LOCKOP	EndChamberTB	54	83	3134						

Multi-Cut Tow

Multi-cut tows are larger commercial vessels which can carry more barges and cannot be fitted into the chamber with one cut. Each multi-cut tow in DLM passes through approach (fly/exchange/turnbak), entry, chambering, exit (fly/exchange/turnback) as well as cut approach and cut extraction in between. It is noted that the operation of a "cut approach" is for the next to the last cut. The 1st cut approach is included in the overall approach. However, the operation of "cut extraction" is for the 1st cut to the cut before last cut. The last cut extraction is included in the overall exit.

Table 34 Vessel Log of Multi-Cut Tow

	B	C	D	E	F	G	H	I	J	K	L	M
1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
3979	244.5	PROCREACH	ArriveLock	54	83	81	T	11	S	Up	3	
3980	244.5	LOCKOP	StartChamberTB	54	83	81	T	11	S	Up	3	1
3981	244.5	LOCKOP	StartFlyApp	54	83	81	T	11	S	Up	3	
3982	244.6667	LOCKOP	EndChamberTB	54	83	81	T	11	S	Up	3	
3983	244.7833	LOCKOP	EndFlyApp	54	83	81	T	11	S	Up	3	
3984	244.7833	LOCKOP	StartEntry	54	83	81	T	11	S	Up	3	1
3985	244.8833	LOCKOP	EndEntry	54	83	81	T	11	S	Up	3	1
3986	244.8833	LOCKOP	StartChambering	54	83	81	T	11	S	Up	3	1
3987	245	LOCKOP	EndChambering	54	83	81	T	11	S	Up	3	1
3988	245	LOCKOP	StartCutExtr	54	83	81	T	11	S	Up	3	1
3989	245.0833	LOCKOP	EndCutExtr	54	83	81	T	11	S	Up	3	1
3990	245.0833	LOCKOP	StartChamberTB	54	83	81	T	11	S	Up	3	1
3991	245.25	LOCKOP	EndChamberTB	54	83	81	T	11	S	Up	3	
3992	245.25	LOCKOP	StartCutApp	54	83	81	T	11	S	Up	3	2
3993	245.2833	LOCKOP	EndCutApp	54	83	81	T	11	S	Up	3	2
3994	245.2833	LOCKOP	StartEntry	54	83	81	T	11	S	Up	3	2
3995	245.4833	LOCKOP	EndEntry	54	83	81	T	11	S	Up	3	2
3996	245.4833	LOCKOP	StartChambering	54	83	81	T	11	S	Up	3	2
3997	245.6	LOCKOP	EndChambering	54	83	81	T	11	S	Up	3	2
3998	245.6	LOCKOP	StartCutExtr	54	83	81	T	11	S	Up	3	2
3999	245.85	LOCKOP	EndCutExtr	54	83	81	T	11	S	Up	3	2
4000	245.85	LOCKOP	StartChamberTB	54	83	81	T	11	S	Up	3	2
4001	246.0167	LOCKOP	EndChamberTB	54	83	81	T	11	S	Up	3	
4002	246.0167	LOCKOP	StartCutApp	54	83	81	T	11	S	Up	3	3
4003	246.0667	LOCKOP	EndCutApp	54	83	81	T	11	S	Up	3	3
4004	246.0667	LOCKOP	StartEntry	54	83	81	T	11	S	Up	3	3
4005	246.1167	LOCKOP	EndEntry	54	83	81	T	11	S	Up	3	3
4006	246.1167	LOCKOP	StartChambering	54	83	81	T	11	S	Up	3	3
4007	246.25	LOCKOP	EndChambering	54	83	81	T	11	S	Up	3	3
4008	246.25	LOCKOP	StartFlyExit	54	83	81	T	11	S	Up	3	3
4009	246.3333	LOCKOP	EndFlyExit	54	83	81	T	11	S	Up	3	
4010	246.3333	LEAVEREACH	LeaveLock	54		81						

	B	C	D	E	F	G	H	I	J	K	L	M
1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID
4680	270	PROCREACH	ArriveLock	54		1016	T	11	S	Up	1	
4689	270.3523	LOCKOP	StartTBPreApp	54	83	1016	T	11	S	Up	3	
4701	270.8023	LOCKOP	EndTBPreApp	54	83	1016	T	11	S	Up	3	
4712	271.1356	LOCKOP	StartCutApp	54	83	1016	T	11	S	Up	3	1
4713	271.1523	LOCKOP	EndCutApp	54	83	1016	T	11	S	Up	3	1
4714	271.1523	LOCKOP	StartEntry	54	83	1016	T	11	S	Up	3	1
4719	271.2856	LOCKOP	EndEntry	54	83	1016	T	11	S	Up	3	1
4720	271.2856	LOCKOP	StartChambering	54	83	1016	T	11	S	Up	3	1
4725	271.4023	LOCKOP	EndChambering	54	83	1016	T	11	S	Up	3	1
4726	271.4023	LOCKOP	StartCutExtr	54	83	1016	T	11	S	Up	3	1
4729	271.5356	LOCKOP	EndCutExtr	54	83	1016	T	11	S	Up	3	1
4730	271.5356	LOCKOP	StartChamberTB	54	83	1016	T	11	S	Up	3	1
4733	271.7023	LOCKOP	EndChamberTB	54	83	1016	T	11	S	Up	3	
4734	271.7023	LOCKOP	StartCutApp	54	83	1016	T	11	S	Up	3	2
4737	271.7356	LOCKOP	EndCutApp	54	83	1016	T	11	S	Up	3	2
4738	271.7356	LOCKOP	StartEntry	54	83	1016	T	11	S	Up	3	2
4743	271.8856	LOCKOP	EndEntry	54	83	1016	T	11	S	Up	3	2
4744	271.8856	LOCKOP	StartChambering	54	83	1016	T	11	S	Up	3	2
4747	272.0189	LOCKOP	EndChambering	54	83	1016	T	11	S	Up	3	2
4748	272.0189	LOCKOP	StartCutExtr	54	83	1016	T	11	S	Up	3	2
4756	272.2023	LOCKOP	EndCutExtr	54	83	1016	T	11	S	Up	3	2
4757	272.2023	LOCKOP	StartChamberTB	54	83	1016	T	11	S	Up	3	2
4762	272.3689	LOCKOP	EndChamberTB	54	83	1016	T	11	S	Up	3	
4763	272.3689	LOCKOP	StartCutApp	54	83	1016	T	11	S	Up	3	3
4764	272.4023	LOCKOP	EndCutApp	54	83	1016	T	11	S	Up	3	3
4765	272.4023	LOCKOP	StartEntry	54	83	1016	T	11	S	Up	3	3
4766	272.4356	LOCKOP	EndEntry	54	83	1016	T	11	S	Up	3	3
4767	272.4356	LOCKOP	StartChambering	54	83	1016	T	11	S	Up	3	3
4770	272.5689	LOCKOP	EndChambering	54	83	1016	T	11	S	Up	3	3
4771	272.5689	LOCKOP	StartTBExit	54	83	1016	T	11	S	Up	3	3
4775	272.8189	LOCKOP	EndTBExit	54	83	1016	T	11	S	Up	3	
4776	272.8189	LOCKOP	StartChamberTB	54	83	1016	T	11	S	Up	3	3
4777	272.8189	LOCKOP	StartTBPostExit	54	83	1016	T	11	S	Up	3	
4780	272.8773	LOCKOP	EndTBPostExit	54	83	1016	T	11	S	Up	3	
4781	272.8773	LEAVEREACH	LeaveLock	54		1016						
4786	272.9523	LOCKOP	EndChamberTB	54	83	1016						

Recreational Vessels

There are various ways for recreational vessels to pass through the lock chambers: as single recreational lockage, as multi-recreational lockage and as part of commercial lockage, such as participating in mixed-vessel lockage or being in chamber turnback between cuts of multi-cut vessel or between vessels. The following examples show some outputs of recreational lockages which fall into some of those categories. If a recreational vessel is locked during the chamber turnback, it leaves the lock immediately at the end of chamber turnback.

- Locking with its own RecSOL (start of lockage for recreational vessel) and RecEOL (end of lockage for recreational vessel) (as shown in Table 35 (a))
- Participating in multi-recreational lockage with one other recreational vessel which has RecSOL and RecEOL
- During the chamber turnback without RecSOL and RecEOL
    - Between cuts (as shown in Table 35 (b)-1)
    - Between vessels (as shown in Table 35 (b)-2)
- Participating in mixed-vessel lockage with commercial tows

Table 35 Vessel Log of Recreational Vessels

(a) Single Recreational Lockage

	B	C	D	E	F	G	H	I	J	K	L
1	EventTime	EventType	LockEventType	LockID	ChamberID	VesselID	VesselType	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts
19572	4164.3833	PROCREACH	ArriveLock	54	84	6607	R	10	R	Up	1
19573	4164.3833	LOCKOP	RecSOL	54	84	6607	R	10	R	Up	1
19574	4164.5167	LOCKOP	RecEOL	54	84	6607	R	10	R	Up	1
19575	4164.5167	LEAVEREACH	LeaveLock	54		6607					

(b)-1 During Chamber Turnback (between cuts)

	B	D	E	F	G	I	J	K	L	M	P	Q
1	EventTime	LockEventType	LockID	ChamberID	VesselID	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID	MultiRecIDs	TBVesselIDs
62219	5697.0833	ArriveLock	54		6629	10	R	Up	1			
62280	5702.5833	ArriveLock	54	84	5827	11	S	Dn	3			
62284	5702.9167	StartFlyApp	54	84	5827	11	S	Dn	3			
62285	5703.0167	EndFlyApp	54	84	5827	11	S	Dn	3			
62286	5703.0167	StartEntry	54	84	5827	11	S	Dn	3	1		
62291	5703.3167	EndEntry	54	84	5827	11	S	Dn	3	1		
62292	5703.3167	StartChambering	54	84	5827	11	S	Dn	3	1		
62295	5703.4607	EndChambering	54	84	5827	11	S	Dn	3	1		
62296	5703.4607	StartCutExtr	54	84	5827	11	S	Dn	3	1		
62303	5703.8107	EndCutExtr	54	84	5827	11	S	Dn	3	1		
62304	5703.8107	StartChamberTB	54	84	5827	11	S	Dn	3	1		& 6629(R)
62307	5703.9107	EndChamberTB	54	84	5827	11	S	Dn	3			& 6629(R)
62308	5703.9107	LeaveLock	54		6629							
62309	5703.9107	StartCutApp	54	84	5827	11	S	Dn	3	2		
62310	5703.9954	EndCutApp	54	84	5827	11	S	Dn	3	2		
62311	5703.9954	StartEntry	54	84	5827	11	S	Dn	3	2		
62312	5704.0314	EndEntry	54	84	5827	11	S	Dn	3	2		
62313	5704.0314	StartChambering	54	84	5827	11	S	Dn	3	2		
62316	5704.0978	EndChambering	54	84	5827	11	S	Dn	3	2		
62317	5704.0978	StartCutExtr	54	84	5827	11	S	Dn	3	2		
62318	5704.1438	EndCutExtr	54	84	5827	11	S	Dn	3	2		
62319	5704.1438	StartChamberTB	54	84	5827	11	S	Dn	3	2		
62324	5704.3313	EndChamberTB	54	84	5827	11	S	Dn	3			

(b)-2 During Chamber Turnback (between vessels)

	B	D	E	F	G	I	J	K	L	M	P	Q
1	EventTime	LockEventType	LockID	ChamberID	VesselID	VesselTypeID	VesselPolicyGroup	Direction	TotalCuts	CutID	MultiRecIDs	TBVesselIDs
61643	5677.6833	ArriveLock	54		6627	10	R	Up	1			
61754	5682.0833	ArriveLock	54	84	2649	11	S	Dn	2			
61755	5682.0833	StartChamberTB	54	84	2649	11	S	Dn	2	1		& 6627(R)
61756	5682.0833	StartFlyApp	54	84	2649	11	S	Dn	2			& 6627(R)
61757	5682.143	EndFlyApp	54	84	2649	11	S	Dn	2			& 6627(R)
61761	5682.2167	EndChamberTB	54	84	2649	11	S	Dn	2			& 6627(R)
61762	5682.2167	LeaveLock	54		6627							
61763	5682.2167	StartCutApp	54	84	2649	11	S	Dn	2	1		
61764	5682.3	EndCutApp	54	84	2649	11	S	Dn	2	1		
61765	5682.3	StartEntry	54	84	2649	11	S	Dn	2	1		
61770	5682.3667	EndEntry	54	84	2649	11	S	Dn	2	1		
61771	5682.3667	StartChambering	54	84	2649	11	S	Dn	2	1		
61781	5682.7	EndChambering	54	84	2649	11	S	Dn	2	1		
61782	5682.7	StartCutExtr	54	84	2649	11	S	Dn	2	1		
61787	5682.8167	EndCutExtr	54	84	2649	11	S	Dn	2	1		
61788	5682.8167	StartChamberTB	54	84	2649	11	S	Dn	2	1		
61793	5682.9833	EndChamberTB	54	84	2649	11	S	Dn	2			

The current shipment list (year 2007) contains 52 recreational vessels but without a long queue for recreational vessels. Thus, there is no example showing multi-recreational lockage or mixed-vessel lockage which allows recreational vessels to be locked with commercial vessels.

Other Tests

In order to test various features modeled in DLM, other model tests are performed.

- Test of various control policies
- Test of navigable pass
- Test of multi-vessel lockage
- Test of mixed-vessel lockage
- Test of recreational lockage
- Test of vessel policies for various vessel types

Test of Control Policies

In addition to FIFO, 6 more control policies are modeled in DLM with static or dynamic control policies. User can specify the control policy in chamber table. Any policy can be operated as static way which does not change the parameter or settings during the simulation. Some policies can be operated dynamically with updating parameters or switching between polices during the simulation. Detailed operation of various control policies are shown in the DLM Phase 2 Report (Wang, Yang, and Schonfeld, February, 2008). Some table names or structures might have been changed in Phase 3 due to recent database reconstruction.

Currently examples of static control policies are listed in *tblLockPolicy* (shown in Table 36). Users can create new policies by changing the policy parameters.

Table 36 Lock Control Policy

	LockPolicyID	LockPolicy	Direction	UpCount	DownCount	LockPolicyDescription	FairnessValue
▶	1	FIFO	0	0	0	FIFO	0
	2	N-Up M-Down	0	3	3	N-Up M-Down	0
	3	N-Up M-Down	0	6	6	N-Up M-Down	0
	4	N-Up M-Down	0	12	12	N-Up M-Down	0
	5	One Way	1	1	0	One Way	8
	6	One Way	2	2	0	One Way	8
	7	Longest Queue	0	0	0	Longest Queue	0
	8	SPF	0	0	0	Shortest Processing Time First	0
	9	FSPF	0	0	0	Fairer Shortest Processing Time First	5
	10	FSPF	0	0	0	Fairer Shortest Processing Time First	7
*	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Users can also create their own dynamic control policies by grouping various static control policies (as shown in Table 37) and setting the thresholds of switching polices (as shown in Table 38). For example, the 1st lock policy group includes four policies: FIFO, 3Up-3Down, 6Up-6Down, and 12Up-12Down. The switching threshold between policies is the queue length. If more than 4 vessels in queue, 3Up-3Down policy is activated; if less than 4 vessels in queue, FIFO is applied. Similarly, the 4th lock policy group is composed by FIFO, SPF, FSPF. The switching threshold between FIFO and SPF is the waiting time spent in queue; and the one between SPF and FSPF is the queue length. If waiting time spent in queue is more than 100 minutes, SPF is applied. Under SPF, if a waiting vessel is bypassed by other vessels more than 7 times, FSPF is applied.

Table 37 Lock Policy Group

	LockPolicyGrou...	LockPolicyGroupDesc
▶	1	FIFO / 3-level N-up M-down
	2	FIFO / 2-level N-up M-down
	3	FIFO / SPF
	4	FIFO / SPF / FSPF
*	NULL	NULL

Table 38 Dynamic Lock Control Policy

	LockPolicyDyna...	LockPolicyGrou...	LockPolicyID	ThresholdType	QueueTH	TimeTH
▶	1	1	1	Q	0	0
	2	1	2	Q	4	0
	3	1	3	Q	7	0
	4	1	4	Q	13	0
	5	2	1	Q	0	0
	6	2	2	Q	5	0
	7	2	3	Q	8	0
	8	3	1	T	0	0
	9	3	8	T	0	100
	10	4	1	T	0	0
	11	4	8	T	0	100
	12	4	9	Q	7	0
*	NULL	NULL	NULL	NULL	NULL	NULL

Test of Navigable Pass

It is simple to test the navigable pass by just specifying its schedule with start and end times for navigable pass (as shown in Table 12). There is no cuts information as well as detailed lockage components recorded during the navigable pass. If vessels are still in the middle of lockage when scheduled navigable pass starts, vessels waiting in queue starts navigable pass upon the completion of on-going regular lockages.

Table 39 shows the example output of navigable pass where all the vessels start with SOL and end with EOL. When navigable pass starts at time point of 4560, there are still vessels in the middle of their lockages, vessel #6065 in auxiliary chamber and vessel # 2231 in main chamber. Both vessels end their lockages with fly exits if scheduled navigable pass has started. The following vessels are then locked with the navigable pass simply recorded by SOL and EOL. When the navigable pass ends, normal lockage is applied to the arriving vessels. As can be seen in the table, the first arriving vessel after the end of the navigable pass starts its fly approach and asks for chamber turnback since the previous exiting vessel travels the same direction as current vessel.

Table 39 Vessels with Navigable Pass

1	EventTime	EventType	LockEventTyp	LockID	Chamber	Vessel	VesselT	VesselT	Vessel	Directi	TotalCu	CutID
30227	4560	StartNavigablePass										
30228	4560	PROCREACH	ArriveLock	54		3364	T	11	S	Dn	1	
30229	4560.0351	LOCKOP	EndChambering	54	84	6065	T	11	S	Up	5	5
30230	4560.0351	LOCKOP	StartFlyExit	54	84	6065	T	11	S	Up	5	5
30231	4560.0433	LOCKOP	EndCutExtr	54	83	2231	T	11	S	Up	5	4
30232	4560.0433	LOCKOP	StartChamberTB	54	83	2231	T	11	S	Up	5	4
30233	4560.1018	LOCKOP	EndFlyExit	54	84	6065	T	11	S	Up	5	
30234	4560.1018	LEAVEREACH	LeaveLock	54		6065						
30235	4560.1018	LOCKOP	SOL	54		323	T	11	S	Up	1	
30236	4560.1851	LOCKOP	EOL	54		323	T	11	S	Up	1	
30237	4560.1851	LEAVEREACH	LeaveLock	54		323						
30238	4560.1851	LOCKOP	SOL	54		3364	T	11	S	Dn	1	
30239	4560.21	LOCKOP	EndChamberTB	54	83	2231	T	11	S	Up	5	
30240	4560.21	LOCKOP	StartCutApp	54	83	2231	T	11	S	Up	5	5
30241	4560.2267	LOCKOP	EndCutApp	54	83	2231	T	11	S	Up	5	5
30242	4560.2267	LOCKOP	StartEntry	54	83	2231	T	11	S	Up	5	5
30243	4560.2518	LOCKOP	EOL	54		3364	T	11	S	Dn	1	
30244	4560.2518	LEAVEREACH	LeaveLock	54		3364						
30245	4560.31	LOCKOP	EndEntry	54	83	2231	T	11	S	Up	5	5
30246	4560.31	LOCKOP	StartChambering	54	83	2231	T	11	S	Up	5	5
30247	4560.4433	LOCKOP	EndChambering	54	83	2231	T	11	S	Up	5	5
30248	4560.4433	LOCKOP	StartFlyExit	54	83	2231	T	11	S	Up	5	5
30249	4560.5933	LOCKOP	EndFlyExit	54	83	2231	T	11	S	Up	5	
30250	4560.5933	LEAVEREACH	LeaveLock	54		2231						
30251	4563.6667	PROCREACH	ArriveLock	54		4053	T	11	S	Dn	1	
30252	4563.6667	LOCKOP	SOL	54		4053	T	11	S	Dn	1	
30253	4563.7333	LOCKOP	EOL	54		4053	T	11	S	Dn	1	
30254	4563.7333	LEAVEREACH	LeaveLock	54		4053						
30255	4564.0833	PROCREACH	ArriveLock	54		324	T	11	S	Dn	1	
30256	4564.0833	LOCKOP	SOL	54		324	T	11	S	Dn	1	
30257	4564.0969	LOCKOP	EOL	54		324	T	11	S	Dn	1	
30258	4564.0969	LEAVEREACH	LeaveLock	54		324						

1	EventTime	EventType	LockEventTyp	LockID	Chamber	Vessel	VesselT	VesselT	Vessel	Directi	TotalCu	CutID
30463	4629.8333	PROCREACH	ArriveLock	54		830	T	11	S	Up	1	
30464	4629.8333	LOCKOP	SOL	54		830	T	11	S	Up	1	
30465	4629.85	LOCKOP	EOL	54		830	T	11	S	Up	1	
30466	4629.85	LEAVEREACH	LeaveLock	54		830						
30467	4632	EndNavigablePass										
30468	4632.4167	PROCREACH	ArriveLock	54	83	331	T	11	S	Up	4	
30469	4632.4167	LOCKOP	StartChamberTB	54	83	331	T	11	S	Up	4	1
30470	4632.4167	LOCKOP	StartFlyApp	54	83	331	T	11	S	Up	4	
30471	4632.5833	LOCKOP	EndChamberTB	54	83	331	T	11	S	Up	4	
30472	4632.9167	LOCKOP	EndFlyApp	54	83	331	T	11	S	Up	4	
30473	4632.9167	LOCKOP	StartEntry	54	83	331	T	11	S	Up	4	1
30474	4633.0667	LOCKOP	EndEntry	54	83	331	T	11	S	Up	4	1

Test of Multi-Recreational Lockage

Some of the model logic will only be applied if there are enough queues. For example, in order to pack recreational vessels in group, a recreational queue should be formed during the simulation. As shown above, the shipment list for the year 2007 only contains 52 recreational vessels but without long queue (due to the long headways between arrivals). Therefore, in order to test the multi-recreational lockage, more recreational vessels with close headways should be generated.

In this test, an "Additional-Vessel Generator" is added in DLM to create more vessels in addition to the given shipment list. Whenever there is a recreational vessel arriving at lock, the "Additional-Vessel Generator" will duplicate numbers of recreational vessels with chronological orders of arrival times, such as every 3 minutes. With this test generator, it is more likely to have long queue of recreational vessels and to perform multi-recreational lockage.

The parameters of chamber length and user-input number of recreational vessels being packed for each 100 feet determine the number of recreational vessels included in a multi-recreational lockage. If chamber length is 360 feet and at most one recreational vessel can be fit per 100 feet, there could be up to 3 recreational vessels (including the 1st one) in one recreational lockage. That is, there are at most 2 vessels, which are locked with the 1st vessel, in the column of MultiRecID. Similarly, if 2 recreational vessels are specified per 100 feet, there could be up to 6 recreational vessels in one recreational lockage. Table 40 shows some output examples of the multi-recreational lockage. When vessel #6754 starts its recreational lockage, vessel #6605, #6647, #6648 and #6649 are locked with the vessel #6754 in the same recreational lockage. All the five vessels then leave the lock at the same time at the end of lockage even coming with various arrival times.

Table 40 Multi-Recreational Lockage (2 Recs per 100')

	B	D	E	F	G	H	I	J	K	L	M	P
1	EventTime	LockEventType	LockID	Chambe	Vessel	VesselT	VesselT	Vessel	Directio	TotalCu	CutID	MultiRecIDs
21811	4158.8333	ArriveLock	54		6605	R	10	R	Dn	1		
21821	4159.0333	ArriveLock	54		6747	R	10	R	Dn	1		
21822	4159.0833	ArriveLock	54		6748	R	10	R	Up	1		
21825	4159.1333	ArriveLock	54		6749	R	10	R	Dn	1		
21826	4159.1833	ArriveLock	54		6750	R	10	R	Dn	1		
21836	4159.3833	ArriveLock	54	84	6754	R	10	R	Dn	1		
21837	4159.3833	RecSOL	54	84	6754	R	10	R	Dn	1		& 6605(R) & 6747(R) & 6749(R) & 6750(R) & 6751(R)
21838	4159.4	RecEOL	54	84	6754	R	10	R	Dn	1		& 6605(R) & 6747(R) & 6749(R) & 6750(R) & 6751(R)
21839	4159.4	LeaveLock	54		6754							
21840	4159.4	LeaveLock	54		6605							
21841	4159.4	LeaveLock	54		6747							
21842	4159.4	LeaveLock	54		6749							
21843	4159.4	LeaveLock	54		6750							

The operation of packing multiple recreational vessels is also applied to the turnback lockage which recreational vessels can be locked during the chamber turnback. Table 41 shows multiple recreational vessels are locked in the chamber turnback between cuts of vessel #1799. Between 1st and 2nd cuts, six recreational vessels #6617, #7104, #7104, #7106, #7107 and #7111 are locked during the chamber turnback and leave the lock at the end of the chamber turnback. Similarly, six recreational vessels #7114, #7115, #7116, #7117, #7119 and #7120 are locked during the chamber turnback between 2nd and 3rd cuts and leave the lock at the end of chamber turnback. Vessel #1799 leaves the lock after finishing the three-cut lockage.

Table 41 Turnback Lockage with Multiple Recreational vessels

B	D	E	F	G	H	I	J	K	L	M	Q
EventTime	LockEventType	LockID	Chambe	Vessel	VesselT	VesselT	Vessel	Directio	TotalCu	CutID	TBVesselIDs
4509.3333	ArriveLock	54		1799	T	11	S	Up	1		
4515.5833	ArriveLock	54		6617	R	10	R	Dn	1		
4515.6333	ArriveLock	54		7104	R	10	R	Dn	1		
4515.6833	ArriveLock	54		7105	R	10	R	Dn	1		
4515.7333	ArriveLock	54		7106	R	10	R	Dn	1		
4515.7833	ArriveLock	54		7107	R	10	R	Dn	1		
4515.9111	StartExchApp	54	84	1799	T	11	S	Up	3		
4515.9278	EndExchApp	54	84	1799	T	11	S	Up	3		
4515.9278	StartEntry	54	84	1799	T	11	S	Up	3	1	
4515.9833	ArriveLock	54		7111	R	10	R	Dn	1		
4516.0945	EndEntry	54	84	1799	T	11	S	Up	3	1	
4516.0945	StartChambering	54	84	1799	T	11	S	Up	3	1	
4516.1333	ArriveLock	54		7114	R	10	R	Dn	1		
4516.1833	ArriveLock	54		7115	R	10	R	Dn	1		
4516.2278	EndChambering	54	84	1799	T	11	S	Up	3	1	
4516.2278	StartCutExtr	54	84	1799	T	11	S	Up	3	1	
4516.2333	ArriveLock	54		7116	R	10	R	Dn	1		
4516.2833	ArriveLock	54		7117	R	10	R	Dn	1		
4516.3111	EndCutExtr	54	84	1799	T	11	S	Up	3	1	
4516.3111	StartChamberTB	54	84	1799	T	11	S	Up	3	1	& 6617(R) & 7104(R) & 7105(R) & 7106(R) & 7107(R) & 7111(R)
4516.3486	EndChamberTB	54	84	1799	T	11	S	Up	3		& 6617(R) & 7104(R) & 7105(R) & 7106(R) & 7107(R) & 7111(R)
4516.3486	LeaveLock	54		6617							
4516.3486	LeaveLock	54		7104							
4516.3486	LeaveLock	54		7105							
4516.3486	LeaveLock	54		7106							
4516.3486	LeaveLock	54		7107							
4516.3486	LeaveLock	54		7111							
4516.3486	StartCutApp	54	84	1799	T	11	S	Up	3	2	
4516.3833	ArriveLock	54		7119	R	10	R	Dn	1		
4516.4333	ArriveLock	54		7120	R	10	R	Dn	1		
4516.4653	EndCutApp	54	84	1799	T	11	S	Up	3	2	
4516.4653	StartEntry	54	84	1799	T	11	S	Up	3	2	
4516.5986	EndEntry	54	84	1799	T	11	S	Up	3	2	
4516.5986	StartChambering	54	84	1799	T	11	S	Up	3	2	
4516.7319	EndChambering	54	84	1799	T	11	S	Up	3	2	
4516.7319	StartCutExtr	54	84	1799	T	11	S	Up	3	2	
4516.8486	EndCutExtr	54	84	1799	T	11	S	Up	3	2	
4516.8486	StartChamberTB	54	84	1799	T	11	S	Up	3	2	& 7114(R) & 7115(R) & 7116(R) & 7117(R) & 7119(R) & 7120(R)
4516.8819	EndChamberTB	54	84	1799	T	11	S	Up	3		& 7114(R) & 7115(R) & 7116(R) & 7117(R) & 7119(R) & 7120(R)
4516.8819	LeaveLock	54		7114							
4516.8819	LeaveLock	54		7115							
4516.8819	LeaveLock	54		7116							
4516.8819	LeaveLock	54		7117							
4516.8819	LeaveLock	54		7119							
4516.8819	LeaveLock	54		7120							
4516.8819	StartCutApp	54	84	1799	T	11	S	Up	3	3	
4517.2153	EndCutApp	54	84	1799	T	11	S	Up	3	3	
4517.2153	StartEntry	54	84	1799	T	11	S	Up	3	3	
4517.2912	EndEntry	54	84	1799	T	11	S	Up	3	3	
4517.2912	StartChambering	54	84	1799	T	11	S	Up	3	3	
4517.5412	EndChambering	54	84	1799	T	11	S	Up	3	3	
4517.5412	StartFlyExit	54	84	1799	T	11	S	Up	3	3	
4517.5745	EndFlyExit	54	84	1799	T	11	S	Up	3		
4517.5745	LeaveLock	54		1799							

Test of Multi-Vessel Lockage

In DLM, one-cut commercial vessels can participate in multi-vessel lockage. In order to pack multiple small vessels in one lockage, there should be queue for smaller commercial vessels during the simulation. The parameters of chamber dimension, vessel dimension, queue search length and maximum number of vessels allowed to participate in one multi-vessel lockage determine the number and identity of vessels which can be locked through in one multi-vessel lockage.

Table 42 shows the example outputs for multi-vessel lockage. As can be seen, for vessel #9609 we have a multi-vessel lockage with vessel #1801. Both vessels are one-cut commercial vessels. Right before the start of lockage, several recreational vessels (#7024, #7025, #7026, #7027, #7028, and #7029) are locked during the chamber turnback which makes the chamber be ready for the vessel’s fly approach. When vessel #9609, as the first vessel, starts its approach, it looks for a qualified vessel in the waiting queue. Vessel #1801 is then located as the second vessel in current lockage. Since the maximum number of vessels participating multi-vessel lockage is set as 2 at the Marmet Lock, vessel #1801 is packed with vessel #9609 in one lockage, without further search among all other waiting vessels. At the end of lockage, both vessels leave the lock when they end their exit together.

Table 42 Multi-Vessel Lockage

	D	E	F	G	H	J	K	L	M	N	Q
1	LockEventType	LockID	Chambe	Vessel	VesselT	Vessel	Directio	TotalCu	CutID	MultiVesselID	TBVesselIDs
32627	ArriveLock	54		1801	T	S	Up	1			
32709	ArriveLock	54	84	9609	T	S	Up	1			
32710	StartChamberTB	54	84	9609	T	S	Up	1	1		& 7124(R) & 7125(R) & 7126(R) & 7127(R) & 7128(R) & 7129(R)
32711	StartFlyApp	54	84	9609	T	S	Up	1		& 1801(T)	& 7124(R) & 7125(R) & 7126(R) & 7127(R) & 7128(R) & 7129(R)
32712	EndChamberTB	54	84	9609	T	S	Up	1		& 1801(T)	& 7124(R) & 7125(R) & 7126(R) & 7127(R) & 7128(R) & 7129(R)
32725	EndFlyApp	54	84	9609	T	S	Up	1		& 1801(T)	
32726	StartEntry	54	84	9609	T	S	Up	1	1	& 1801(T)	
32729	EndEntry	54	84	9609	T	S	Up	1	1	& 1801(T)	
32730	StartChambering	54	84	9609	T	S	Up	1	1	& 1801(T)	
32737	EndChambering	54	84	9609	T	S	Up	1	1	& 1801(T)	
32738	StartFlyExit	54	84	9609	T	S	Up	1	1	& 1801(T)	
32748	EndFlyExit	54	84	9609	T	S	Up	1		& 1801(T)	
32749	LeaveLock	54		9609							
32750	LeaveLock	54		1801							

Test of Mixed-Vessel Lockage

Unlike multi-vessel lockage, mixed-vessel lockage is performed for non-commercial vessels or a mix of commercial and non-commercial vessels. That is, recreational vessels can be packed with a commercial tow in a mixed vessel lockage. In fact, multi-recreational lockage is a special case of mixed vessel lockage. If the 1st selected vessel is a recreational vessel, it will be a multi-recreational lockage, without any commercial tow being packed. However, if the 1st selected vessel is a commercial tow and there are no qualified commercial tows for multi-vessel lockage, recreational vessels are considered to be packed with selected commercial vessel to form a mixed-vessel lockage.

Similarly, in order to pack multiple small vessels in one lockage, there should be queue for smaller commercial vessels during the simulation. The parameters of chamber dimension and vessel dimension determine the number and identity of vessels which can be locked through in one mixed-vessel lockage. There is no limitation in queue search length and number of participating vessels.

Table 43 shows the example outputs of mixed-vessel lockage. As can be seen, lockage for vessel #2420 is a mixed-vessel lockage with vessel #6641. Vessel #2420 is a commercial one-cut tow and #6641 is a recreational vessel. At the end of the lockage, several recreational vessels (#9831 and #9836) are locked during the chamber turnback which readies the chamber for the next vessel's turnback approach.

Table 43 Mixed-Vessel Lockage

	B	D	E	F	G	H	J	K	L	M	O	P	Q
1	EventTime	LockEventType	LockID	Chambe	Vessel	VesselType	Vessel	Direction	TotalCuts	CutID	MixedVesselIDs	MultiRe	TBVesselIDs
39430	5655.3333	ArriveLock	54		2420	T	S	Dn	1				
50726	6349.0667	ArriveLock	54		6641	R	R	Dn	1				
56231	6681.0298	StartExchApp	54	83	2420	T	S	Dn	1		& 6641(R)		
56232	6681.0798	EndExchApp	54	83	2420	T	S	Dn	1		& 6641(R)		
56233	6681.0798	StartEntry	54	83	2420	T	S	Dn	1	1	& 6641(R)		
56234	6681.1965	EndEntry	54	83	2420	T	S	Dn	1	1	& 6641(R)		
56235	6681.1965	StartChambering	54	83	2420	T	S	Dn	1	1	& 6641(R)		
56237	6681.3631	EndChambering	54	83	2420	T	S	Dn	1	1	& 6641(R)		
56238	6681.3631	StartTBExit	54	83	2420	T	S	Dn	1	1	& 6641(R)		
56241	6681.5298	EndTBExit	54	83	2420	T	S	Dn	1		& 6641(R)		
56242	6681.5298	StartChamberTB	54	83	2420	T	S	Dn	1	1	& 6641(R)		& 9831(T) & 9836(T)
56243	6681.5298	StartTBPostExit	54	83	2420	T	S	Dn	1		& 6641(R)		& 9831(T) & 9836(T)
56244	6681.5641	EndTBPostExit	54	83	2420	T	S	Dn	1		& 6641(R)		& 9831(T) & 9836(T)
56245	6681.5641	LeaveLock	54		2420								
56246	6681.5641	LeaveLock	54		6641								
56247	6681.7298	EndChamberTB	54	83	2420								

Test of Various Vessel Types and Policies

As shown above, the shipment list for year 2007 only contains no high priority vessels. Therefore, in order to test the special policy for high priority vessels, some high priority vessels are generated. When checking the available distribution provided in *tblChamberOpsLevel10*, we find processing time distributions for federal government vessels (vessel type ID = 4) only, but not for other priority vessels such as passenger vessels. Thus only extra federal government vessels are generated in addition to the given shipment list.

According to the definition from *tblVesselType*, federal government vessels are non-commercial vessels in the “high priority” vessel policy group That is, they have the highest priority to be locked through chamber even when they arrive later than other commercial tows. In addition, federal government vessels can participate in mixed-vessel lockages, but not in multi-vessel lockages due to their non-commercial vessel attribute.

Table 44 shows the example of lockage process for high priority vessel. Vessel #7421 arrives at lock later then vessel #3320. With its priority features, vessel # 7421 is processed ahead of vessel #3320. During the lockage, several recreational vessels are locked together with vessel #7421 since they are all non-commercial vessels.

Table 44 Lockage of High Priority Vessels

	B	D	E	F	G	H	I	J	K	L	M	O
1	EventTime	LockEventType	LockID	Chambe	Vessel	VesselT	VesselT	Vessel	Directi	TotalCu	CutID	MixedVesselIDs
5396	4036.0833	ArriveLock	54		3320	T	11	S	Up	1		
7317	4147.75	ArriveLock	54		7421	G	4	H	Dn	1		
7337	4149.1449	StartExchApp	54	83	7421	G	4	H	Dn	1		& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7338	4149.3487	EndExchApp	54	83	7421	G	4	H	Dn	1		& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7339	4149.3487	StartEntry	54	83	7421	G	4	H	Dn	1	1	& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7340	4149.5654	EndEntry	54	83	7421	G	4	H	Dn	1	1	& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7341	4149.5654	StartChambering	54	83	7421	G	4	H	Dn	1	1	& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7342	4149.7821	EndChambering	54	83	7421	G	4	H	Dn	1	1	& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7343	4149.7821	StartExchExit	54	83	7421	G	4	H	Dn	1	1	& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7345	4150.2382	EndExchExit	54	83	7421	G	4	H	Dn	1		& 6604(R) & 6675(R) & 6678(R) & 6680(R)
7346	4150.2382	LeaveLock	54		7421							
7351	4150.2382	StartExchApp	54	83	3320	T	11	S	Up	3		
7352	4150.7382	EndExchApp	54	83	3320	T	11	S	Up	3		
7353	4150.7382	StartEntry	54	83	3320	T	11	S	Up	3	1	
7354	4150.7882	EndEntry	54	83	3320	T	11	S	Up	3	1	
7355	4150.7882	StartChambering	54	83	3320	T	11	S	Up	3	1	
7356	4150.9215	EndChambering	54	83	3320	T	11	S	Up	3	1	
7357	4150.9215	StartCutExtr	54	83	3320	T	11	S	Up	3	1	
7358	4151.0048	EndCutExtr	54	83	3320	T	11	S	Up	3	1	
7359	4151.0048	StartChamberTB	54	83	3320	T	11	S	Up	3	1	
7360	4151.1715	EndChamberTB	54	83	3320	T	11	S	Up	3		
7361	4151.1715	StartCutApp	54	83	3320	T	11	S	Up	3	2	
7362	4151.2048	EndCutApp	54	83	3320	T	11	S	Up	3	2	
7363	4151.2048	StartEntry	54	83	3320	T	11	S	Up	3	2	
7364	4151.3882	EndEntry	54	83	3320	T	11	S	Up	3	2	
7365	4151.3882	StartChambering	54	83	3320	T	11	S	Up	3	2	
7366	4151.4882	EndChambering	54	83	3320	T	11	S	Up	3	2	
7367	4151.4882	StartCutExtr	54	83	3320	T	11	S	Up	3	2	
7369	4151.7715	EndCutExtr	54	83	3320	T	11	S	Up	3	2	
7370	4151.7715	StartChamberTB	54	83	3320	T	11	S	Up	3	2	
7371	4151.9382	EndChamberTB	54	83	3320	T	11	S	Up	3		
7372	4151.9382	StartCutApp	54	83	3320	T	11	S	Up	3	3	
7373	4151.9715	EndCutApp	54	83	3320	T	11	S	Up	3	3	
7374	4151.9715	StartEntry	54	83	3320	T	11	S	Up	3	3	
7375	4152.0382	EndEntry	54	83	3320	T	11	S	Up	3	3	
7376	4152.0382	StartChambering	54	83	3320	T	11	S	Up	3	3	
7377	4152.1548	EndChambering	54	83	3320	T	11	S	Up	3	3	
7378	4152.1548	StartExchExit	54	83	3320	T	11	S	Up	3	3	
7379	4152.3548	EndExchExit	54	83	3320	T	11	S	Up	3		
7380	4152.3548	LeaveLock	54		3320							

Future Development of DLM

After a 3-phase development, the functions provided by the current DLM version satisfy most of the original development goals. There are still some tasks left for future development, such as an independent simulation model or a module of network simulation model. Some of them require data support provided by DAPP. Others are model enhancements in functional and operational aspects. The completed and remaining tasks are listed below.

Completed DLM Development Tasks

Phase 1:

1. Four State / Three Condition Single Cut Lockage Process
2. Multi-Cut Lockages
3. Multiple Vessel Type (DLM policy group)
4. Chamber Preference / Exclusion

Phase 2:

5. First Integration of BasinSym and DLM (Version @ 12/08/2007)
6. Detailed Lockage Time Components
7. Scheduled Major Maintenance Closures
8. Lockage Policies (4)

Phase 3:

9. Lockage Policies (2)
10. Multi-Cut Lockage Efficiency Enhancements
11. Navigable Pass
12. Rec Rules and Multi-Rec Lockage
13. Multi-Vessel Lockage
14. Mixed-Vessel Lockage
15. Interference
16. Vessel Policy for Various Vessel Types (not restricted to Rec)
17. Lockage during Chamber Turnback
    a. Multi-Rec
    b. Multi-LightBoat
    c. Mixed-Rec-LightBoat

Future Tasks

- Random Minor Closures – need data structure from DAPP and BasinSym classes
- Component Reliability – need BasinSym support
- Lockage type K – need historical data from DAPP
- 14 additional lockage Policies
- Parallel Computing

The biodiversity effect: Do plant species mixtures perform better than monocultures in runoff treatment wetlands?

Basic Information

Title:	The biodiversity effect: Do plant species mixtures perform better than monocultures in runoff treatment wetlands?
Project Number:	2008MD166B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	5th and 8th Congressional District of Maryland
Research Category:	Water Quality
Focus Category:	Treatment, Wetlands, Water Quality
Descriptors:	None
Principal Investigators:	Andrew Baldwin

Publication

Annual Report FY 2009

The biodiversity effect: Do plant species mixtures perform better than monocultures in runoff treatment wetlands?

Reporting period: March 1, 2008-February 28, 2009
Project duration: March 1, 2008-February 28, 2010

Prepared for:
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Background Information

GOAL

The goal of this research is to examine the role of plant diversity in removal of pollutants in runoff using treatment wetlands. While many studies have reported on the use of wetlands for water quality treatment, none have applied recent scientific evidence linking increased ecosystem function with biological diversity to improving ecologically-based treatment systems.

LITERATURE REVIEW

Nutrient pollution from urban and agricultural runoff threatens water resources in the U.S. and globally. Agricultural applications of nitrogen and phosphorus have grown exponentially over the past several decades and continue to rise (Nielson and Aiertebjerg 1984; D'Elia et al. 1986). EPA's two latest National Water Quality Report to Congress identified urban runoff as a leading source of impairment in streams and agriculture as the top cause of impairment in streams (EPA 2002, 2007a) and EPA's latest report to Congress identified excess nutrients as top contributors to impairment of water bodies nationally (EPA 2007a). Furthermore, the state of Maryland reported non-point sources and nutrient pollution as the top contributors degrading Maryland's waterways (EPA 2007b).

Excessive nitrogen and phosphorus inputs to waterways cause toxic algal blooms and anoxia that harm commercial fishing interests, restrict recreational uses of water resources, threaten human health, and degrade fragile ecosystems (Officer et al. 1984; Nixon, 1995; Sellner, 1997). Non-point sources of pollution, such as runoff from urban and agricultural lands, are a major contributor to water quality problems in the Chesapeake Bay. The Maryland Department of Natural Resources estimates that 39% of nitrogen and 43% of phosphorus entering the Chesapeake Bay are derived from agricultural sources and 16% of total nitrogen and 24% of total phosphorus are derived from urban runoff (Maryland Department of Natural Resources 2003).

Constructed wetlands provide an economically viable alternative to conventional treatment methods for substantially reducing concentrations of nutrients, solids, and oxygen-demanding substances in agricultural and urban runoff (Hammer 1992; Reddy and Kadlec 2001; Jordan et al. 2003; Scholz 2006), animal wastewater (Biddlestone et al. 1991; Newman and Clausen 1997; Shaafsma et al. 1999; Clarke and Baldwin 2002), and domestic wastewater (Moshiri 1993; Kadlec and Knight 1996). Wetlands also trap sediment, decreasing extra sediment loads in downstream water bodies and provide habitat for a variety of common and rare invertebrates, birds, and mammals (Mitsch and Gosselink 2000).

While many studies have examined the efficiency of nutrient and solids removal in constructed wetlands (Moshiri 1993; Kadlec and Knight 1996), little research has been conducted on the effects of different plant species on treatment effectiveness. In addition to uptake of nutrients, wetland plants have a strong influence on nitrogen removal by providing habitat for aerobic and anaerobic microbial communities in close proximity. A common anatomical adaptation of wetland plants to the anaerobic environment surrounding their roots is the development of air-filled tissue (aerenchyma) that allows diffusion of oxygen from leaves and stems to the roots, allowing aerobic respiration to continue (Armstrong 1979; Mendelssohn and Burdick 1988). Some of this oxygen leaks out from the roots, creating an oxygen-rich region around the roots (oxidized rhizosphere) (Mitsch and Gosselink 2000). The presence of oxidized rhizospheres interspersed within the anaerobic soil matrix that develops in flooded soils creates optimal conditions for transformation of ammonium into nitrate by microbial nitrification (aerobic zone) and subsequent conversion of nitrate to nitrogen gas via microbial denitrification (anaerobic zone) (Brix 1993; Mitsch and Gosselink 2000). Microbial transformations are often as or more important than plant uptake for removal of nitrogen (Brix 1993). Furthermore, microbial transformations remove nitrogen from the system, while nutrients from plants will eventually be re-released during decomposition unless they are harvested.

Mixtures of wetland plant species may result in enhanced water quality compared with monocultures because of differences in shoot and root morphology, anatomy, and physiology. For example, a mixture of a deep-rooted species and a shallow-rooted species would be predicted to occupy and extract nutrients from a greater vertical portion of the root zone than either species would alone. Similarly, differences in above-ground plant morphology or shade tolerance might allow greater biomass production (and associated nutrient uptake) than would occur for each species in monoculture.

The effect of higher numbers of species (i.e., species diversity) on the functioning of ecosystems (e.g., nutrient cycling) has become a major topic of scientific interest in the field of ecology during the last decade. However, this scientific knowledge has not been applied to improving water quality using designed ecosystems like treatment wetlands. This proposed research is to our knowledge the first to study how plant diversity can be manipulated in the service of better water quality. The results of this study may therefore have implications for areas of research and engineering beyond those related directly to wetlands and water quality improvement.

OUTCOMES AND BENEFITS

This research supports the program objectives of the Maryland Water Resources Research Center by 1) exploring the link between biodiversity and water quality, an area of research that has received little attention, 2) training and educating a future water scientist, and 3) disseminating best-practice guidelines to managers, scientists, and the public on management of created and restored wetlands.

Specific products of our research that are of interest to managers, scientists, and the general public include: 1. Presentations, papers, and reports describing the role of plant diversity in the effectiveness of wetlands designed for treating urban or agricultural runoff; and 2. A set of recommendations for planting wetlands to improve water quality and calculate removal rate coefficients for use in designing future treatment wetlands.

Additionally, this research is playing an important role the training and education of an M.S. student, Jennifer Brundage, by providing specific experience with experimental design, mesocosm studies, *in situ* monitoring of water quality parameters, growth dynamics of aquatic plants, analysis of water samples for nitrogen and phosphorus, and statistical analysis and interpretation of biological chemical, and physical water quality data. Presentation of research results at national or international scientific meetings is also enhancing Jennifer’s education and training.

ORIGINAL OBJECTIVES AND HYPOTHESES

The overall goal of this research is to investigate the potential for mixtures of plant species in water treatment wetlands to improve nutrient removal from runoff to a greater degree than is possible from traditionally-used plant monocultures. We are examining effects of plant species mixtures on nutrient removal and biomass production using greenhouse mesocosms to simulate constructed wetlands receiving runoff. Our original proposed objectives are to:

Objective 1: Create experimental treatment wetland mesocosms (simulating both surface and subsurface flow wetland configurations) containing different plant diversity treatments, and relate diversity treatments to removal of nutrients from water; and

Objective 2: Develop a set of recommendations for planting wetlands to improve runoff water quality and calculate removal rate coefficients for use in designing future runoff treatment wetlands.

Objective 1 specifically tests the hypothesis that:

H1: Nutrient removal in treatment wetland mesocosms will increase with increasing numbers of planted species per unit area.

If the study demonstrates that mixtures outperform monocultures then it will be possible to make the broader recommendation that treatment wetlands in general be planted with mixtures of species rather than with monocultures. The study will also support recommendations for planting wetlands designed specifically to treat runoff.

Project Update

We began the set up of this experiment in May 2008. Our initial intent was to complete the experiment during the 2008 growing season. However, we had numerous difficulties in the set up of the experiment that have delayed us from starting it. A summary of our activities on the project is presented here (and is illustrated in the project photo gallery that follows):

- We developed several prototype mesocosms in early summer 2008 and decided to set up the mesocosms as free water surface wetlands only (instead of both surface and subsurface wetlands) to simplify operation and maintenance of the experiment.
- Construction of prototypes was delayed due to the busy state of our machine shop.
- Obtaining soil that had not been amended with fertilizer was an unanticipated challenge; soil analyses were conducted for several types of soil.
- Mesocosm tubs were unstable and so had to be reinforced with 2x4 frames (see Photo 1 below).
- Jennifer Brundage, the M.S. student working on the project, presented a poster on the research at two conferences (May and June 2008).
- In July 2008 we were ready to begin the experiment but realized that wetland mesocosm tubs were leaking. After several weeks we were able to install pond liners around the tubs to contain the leaks (see Photo 1 below). Figuring out the best solution to the leak

problem, ordering liners and installing them was a major operation, partly because the tubs full of plants and soil are too heavy to lift. Then bulkhead fittings had to be installed for the outflow to pass through the liner and tubs without leaking.

- In August 2008 realized that inflow tubing was clogged with biofilm so that exact amounts of influent could not be delivered to each tub. Reductions in flow averaged 50% per day.
- Spent the next few months trying different mechanisms to unclog the tubing, including installing a UV filter, washing out the tubing with algicide, fungicide, and bactericide (GreenShield). Classes began again in September, which slowed the work.
- By November it was determined that tubing would need to be scrapped and the entire influent delivery system re-designed. We spent the next few months re-designing the system. By this time plants were beginning to senesce for the winter, so it was determined the most prudent course would be to carefully re-design the experiment and begin to re-run it in 2009.
- After review of additional literature, the experimental mesocosms were redesigned as batch-operated rather than flow-through reactors, avoiding any problems with valve clogging.
- To accommodate this new experimental design the bulkheads are in the process of being moved to a different elevation (to allow drainage of surface water between batches).
- After one attempt at replanting (Photo 3 and 4 below), it was concluded that one of the three species, *Echinochloa*, was unable to grow in polycultures. In March of this year we decided to grow up (from seed) a new species, *Peltandra virginica*, and replace *Echinochloa* with *Peltandra*, which was performed on May 1 (Photo 5 below).
- A no-cost extension will be requested to allow completion of the project in 2009.
- *Peltandra* plants are now established and we plan to begin batch operation in 2 weeks. The experiment will be operated through the rest of the 2009 growing season.

Project Gallery

Photo 1. December 2008. Jenn Brundage (M.S. student) and mesocosms with original plantings. Wooden frames to stabilize tubs and black liners to contain their leakage are visible.

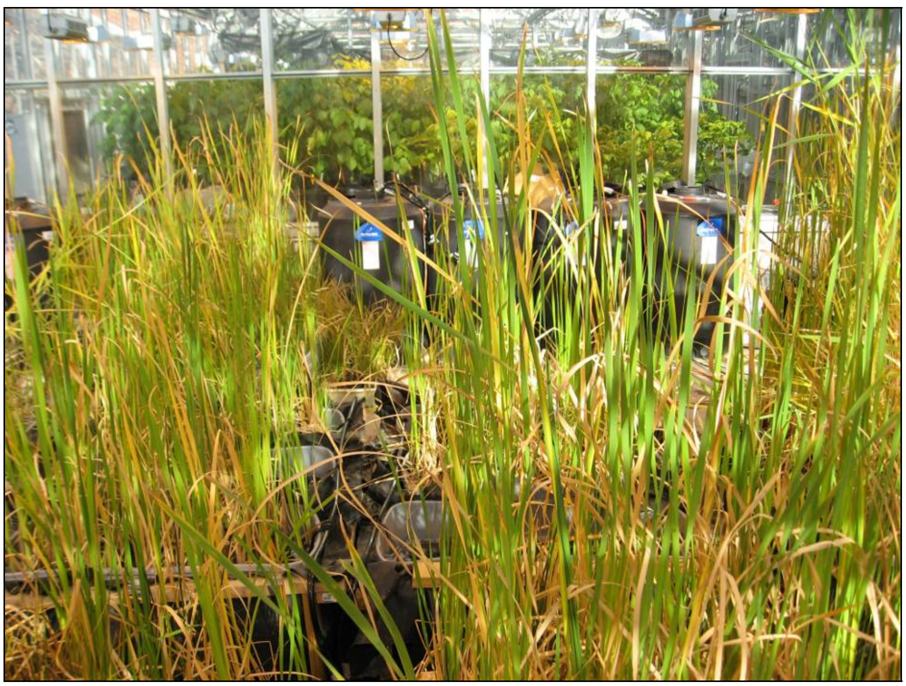

Photo 2. December 2008. Black tanks that were used initially to supply mesocosms with nutrient solutions via pumps are visible behind the plants and mesocosms. The mesocosms had to be converted to batch operation due to persistent clogging of needle valves with biofilms (likely due to the slow flow rates necessary for sufficient hydraulic residence time in the mesocosms).

Photo 3. January 2009. *Echinochloa* seedlings ready to be planted in mesocosm to supplement those that died. Eventually these did not survive well in polyculture so we replaced them with a different species, *Peltandra virginica,* in May.

Photo 4. January 2009. *Typha* and *Juncus* plants were clipped to 40 cm height in to improve growth of planted *Echinochloa* seedlings. However, the seedlings still did not grow well in mixture.

Photo 5. May 2009. *Peltrandra virginica* seedlings (short, oval leaf blades) planted with taller, linear-leaved *Typha* and *Juncus*.

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Microbial nitrogen sequestration in detrital-based streams of the Chesapeake Bay watershed under stress from road-salt runoff.

Basic Information

Title:	Microbial nitrogen sequestration in detrital-based streams of the Chesapeake Bay watershed under stress from road-salt runoff.
Project Number:	2008MD171B
Start Date:	7/1/2008
End Date:	6/30/2009
Funding Source:	104B
Congressional District:	MD 7th
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Ecology, Nutrients
Descriptors:	None
Principal Investigators:	Christopher Swan

Publication

Microbial nitrogen sequestration in detrital-based streams of the Chesapeake Bay watershed under stress from road-salt runoff.

MWRRC Project # 2008MD171B

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Interim Report

Student Support

Four graduate students (Peter Bogush, Carrie DePalma; Robin Van Meter and Jennifer Li) were supported in summer 2008 to work on the project.

News Pieces

National Public Radio – Living on Earth
"Snow and Salt Report"
http://www.loe.org/shows/shows.htm?programID=09-P13-00008#feature9

Baltimore Sun Bay and Environment Blog
"Icy dilemma: Road salt taints streams, reservoirs"
http://weblogs.baltimoresun.com/news/local/bay_environment/blog/2009/03/icy_dilemma_road_salt_taints_s.html

Statement of Water Quality Problem

Headwater streams are known to be especially sensitive to landscape disturbances, as they comprise the vast majority of stream miles in a watershed (Alexander et al., 2000; Peterson et al., 2001). The aggregate effects of human disturbance downstream (e.g., nutrient loading, sedimentation) are mediated by these small streams, and the ecological communities living there (Herlihy et al., 1998). These habitats are hotspots of important processes related to water quality, especially rates of organic matter decomposition and nutrient cycling (Wallace et al., 1980; Alexander et al., 2000; Peterson et al., 2001; Groffman & Mayer, 2005). Therefore, any disturbance disrupting the ecological interactions involved in such processes is likely to be especially pronounced in these small streams, as they are in intimate contact with the landscape. The recently identified effects of road-salt runoff on stream ecosystem processes, by myself and other researchers, is one such stressor (Environment Canada, 2001; Kaushal et al., 2005). Inputs of road-salt are expected to increase as road density increases, and thus the subsequent effects on stream ecosystems important to understand (Kaushal et al., 2005). To date, work in my lab and others has revealed important consequences for both carbon (see below) and nitrogen dynamics as mediated by microbial communities (Hale & Groffman, 2006). However, known interactions between higher trophic-level organisms (e.g., invertebrate consumers) and microbes exist (Ribblett et al., 2005). The goal here will be to measure how interactions between higher trophic-level consumers and microbial communities in streams are altered by salt runoff, and what the subsequent effects are on nitrogen sequestration by stream microbial communities. Specifically, I sought to:

(1) Determine the rate at which nitrogen is sequestered under salt-stressed conditions by microbial communities from multiple streams in the region,

(2) Isolate the contribution of invertebrates to mediating the rate of nitrogen sequestration under salt-stressed conditions, and

(3) Manipulate a range of salt loading reported to occur in the Chesapeake Bay region, and identify the salt level whereby the aforementioned interactions change, thus providing information to guide decisions regarding road salt management and water quality.

Project Objectives

Detritus is relatively poor in essential nutrients such as nitrogen and phosphorus (Ostrofsky 1993; 1997). Experimental work at the reach scale has shown that increasing nitrogen delivery to small, forested streams results in substantial sequestration of nitrogen into the leaf-microbial matrix (Gulis et al., 2004; Greenwood et al, 2007). This happens because fungi and bacteria residing in and on leaf litter remove nitrogen from the water column and incorporate it into biomass (Gulis et al., 2004). Invertebrate consumers, and eventually predators such as salamanders, benefit as this nitrogen is assimilated via consumer-resource and predator-prey interactions (Johnson et al., 2006). These interactions serve to move nitrogen out of the water column and up the food web (Cross et al., 2006). Given this evidence and my previous results showing microbial stress due to the presence of road salt, nitrogen removal by microbes into biomass might also be negatively effected. I performed a set of field and laboratory studies to extend my results on carbon mineralization to learn how a complementary process, nitrogen sequestration by litter-dwelling microbes, is altered by road salt stress. Together, the information gained for both carbon and nitrogen dynamics will paint a clearer picture of how salt loading will impact water quality in the Chesapeake Bay region. My approach was to perform three tasks:

Task I. Incubate leaf litter from a common local tree species (American Beech) in five headwater streams to allow colonization by freshwater fungi and bacteria.

Task II. Subject colonized litter to a gradient in salt stress documented to occur in the region (0, 500, 1000 & 5000 g Cl- l-1) and measured nitrogen uptake by litter-dwelling microbes.

Task III. Isolate invertebrate feeding effects of three common stream invertebrate taxa on the capacity of leaf litter to sequester nitrogen from the water column.

Project Progress to Date

Experimental Approach

To address the above tasks, a multi-factorial experiment was carried out by deploying pre-weighed leaf litter in mesh bags into five local streams, retrieving them after significant microbial colonization has occurred, and subjecting them to a gradient of road salt stress (as NaCl) and invertebrate feeding activity. Nitrogen removal from the water column and subsequent sequestration into biomass was be carried out over a period of 2-4 weeks.

All experimental work has been performed, but measurements of N immobilization by fungi have not yet been acquired from the analytical laboratory at the University of Georgia. These samples are being analyzed after an equipment failure.

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Summer Fellowship: Integrated experimental and mathematical evaluation to improve the fate of the tetrachloroethene at contaminated sites

Basic Information

Title:	Summer Fellowship: Integrated experimental and mathematical evaluation to improve the fate of the tetrachloroethene at contaminated sites
Project Number:	2008MD175B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	MD-5
Research Category:	Engineering
Focus Category:	Groundwater, Toxic Substances, None
Descriptors:	None
Principal Investigators:	Allen Davis, Allen Davis

Publication

Integrated experimental and mathematical evaluations to improve the fate of the important groundwater contaminant tetrachloroethene (PCE) at contaminated sites

Yen-jung Lai, University of Maryland

The solvents, tetrachloroethene (PCE) and trichloroethene (TCE) are widely used in a variety of industries. Due to frequent environmental spills and improper disposal of PCE and TCE, they are among the three most common contaminants of groundwater in the U.S. In particular, PCE and TCE were widely used as metal degreasers at military bases. Thus it is not surprising that Department of Defense sites like Aberdeen Proving Ground and Andrews Airforce Base in Maryland are now dealing with a legacy of PCE and TCE contamination. Due to their chemical resistance and suspected human carcinogenicity, contamination of groundwater with PCE and TCE at these and other sites threatens human and environmental health.

Fortunately, certain bacteria can grow on PCE and TCE by respiring these compounds in the same way that humans respire oxygen. In some cases, the ability of bacteria to respire PCE and TCE can be harnessed to clean-up contaminated groundwater. This type of process is known as bioremediation. However, one challenge to successful bioremediation of PCE and TCE is that some of the bacteria that respire these pollutants convert them to compounds that are still considered toxic, which is unacceptable from a bioremediation standpoint. PCE-respiring bacteria that produce toxic by-products include members of the genera *Desulfuromonas*, *Desulfitobacterium* and *Dehalobacter*, among others. In contrast, members of the genus *Dehalococcoides* appear to be unique in their ability to respire PCE and/or other chlorinated ethenes and completely detoxify them in the process.

At most contaminated sites, multiple PCE-respiring populations are present. Under these conditions, competition between PCE-respiring populations for growth substrates is likely to occur, as shown in Figure 1 for two organisms (*Dehalococcoides ethenogenes* and *Dehalobacter restrictus*) that couple the oxidation of H_2 to the reductive dechlorination of PCE. This is important because if *Dehalobacter restrictus* is the dominant population, the toxic intermediate *cis*-dichloroethene (DCE) will accumulate. In contrast, if *Dehalococcoides ethenogenes* controls the fate of PCE, it will be completely detoxified to the benign product ethene. A better understanding of the factors that determine whether *Dehalococcoides* strains or organisms like *Dehalobacter restrictus* that incompletely detoxify PCE will be dominant in groundwater systems is needed to successfully implement bioremediation of PCE at contaminated sites and protect human health.

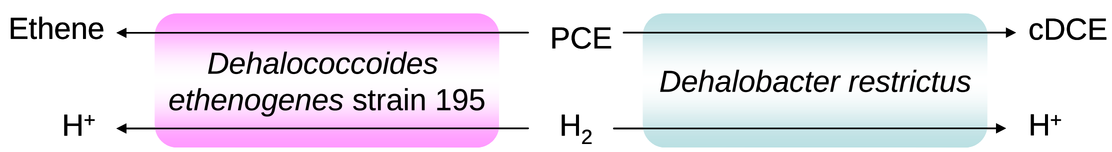

Figure 1. An example of the competitive interactions that may arise when two PCE-respiring populations are present at a contaminated site. In this case *Dehalococcoides ethenogenes* and *Dehalobacter restrictus* compete for both the electron donor (H_2) and the electron acceptor (PCE); however, the end-products of PCE dechlorination differ in the two organisms.

The overall hypothesis of my Ph.D. research is that the kinetic characteristics of PCE-respiring strains and substrate availability will play important roles in determining the outcome of competition between multiple dehalorespiring populations and thus the fate of this important contaminant in the environment. Currently reliable and accurate kinetic parameter estimates are lacking for most of the known PCE-respiring bacterial strain. Therefore, the objectives of my Ph.D project are to: (1) obtain meaningful and unique kinetic parameter estimates to describe PCE-respiring bacteria by two key populations, (*Dehalobacter restrictus* and *Dehalococcoides ethenogenes strain 195)*; (2) use kinetic estimates to theoretically predict outcome of competition in a continuous-flow reactor using mathematical modeling; and (3) validate the model predictions by experimentally evaluating outcome of competition in the completely mixed continuous-flow reactor. I have already made significant progress on achieving objective 1. During summer 2008, I will focus on completing objective 3.

Specifically, I will be experimentally evaluating the outcome of the competition scenario shown in Figure 1 by inoculating an anaerobic, continuous-flow reactor with *Dehalobacter restrictus* and *Dehalococcoides ethenogenes*. H_2 and PCE will be supplied to the reactor in two experiments. H_2 will limit dechlorination in one experiment, and PCE will be the limiting substrate in the other experiment. Each experiment will be run for approximately 60 d. Mathematical modeling suggests that the reactor will reach steady-state with respect to substrate removal and/or one population will washout of the reactor within this timeframe. The kinetic parameter estimates determined as part of this study indicate that *Dehalobacter restrictus* transforms PCE and TCE at a relatively fast rate, but *Dehalococcoides ethenogenes* benefits from being able to grow on DCE, which *Dehalobacter restrictus* cannot transform. Thus, modeling predictions suggest the outcome of competition may depend largely on the relative affinities of the two populations for the limiting substrate.

The modeling predictions will be evaluated using an intensive reactor sampling regimen. Influent and effluent H_2 and chlorinated ethene concentrations will be regularly measured using gas chromatographs equipped with reducing compound photometer and electron capture detectors, respectively. The concentrations of the two PCE-respiring cultures cannot be independently measured using conventional cell-based methods and thus will be determined using a quantitative polymerase chain reaction (qPCR) protocol, which I am currently developing. The experimental data will be compared to the model predictions to determine which factors control the outcome of competition between *Dehalobacter restrictus* and

Dehalococcoides ethenogenes and the fate of PCE.

Finally, the model predictions and experimental results will be integrated and used to develop a set of recommended bioremediation strategies for different site conditions that should lead to complete detoxification of PCE by promoting the growth of *Dehalococcoides* strains. By developing strategies that prevent toxic products of PCE from accumulating, this set of recommendations will help practitioners successfully implement bioremediation of PCE-contamination and lead to improvements in the quality of Maryland's groundwater at sites like Aberdeen Proving Ground and Andrews Air Force Base.

Yen Jung Lai

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EDUCATION

Graduate School
Post-Graduate GPA: 3.53 (includes classes taken as M.S. student at TsingHua University and as Ph.D student at University of Maryland)

Marine-Estuarine-Environmental Sciences Graduate Program, University of Maryland-College Park **2005-present**
Dissertation topic: Kinetics of Hydrogenotrophic Tetrachloroethene-Respiring *Dehalobacter* and *Dehalococcoides* Strains and Their Effects on Competition for Growth Substrates

M.S. in Department of Nuclear Science National TsingHua University, HsinChu, Taiwan, R.O.C **2000-2002**
Thesis Topic: The Influence of Humic acid and Metal Complexes on the Dechlorination of Tetrachloroethylene in Heterogenous System
Undergraduate School
B.S. in Department of Nuclear Science, National TsingHua University,HsinChu, Taiwan, R.O.C **1996-2000**

- Total GPA: 3.54 (out of 4.0)
- Junior–Senior GPA: 3.79 (out of 4.0)
- Ranking: 7^{th} (out of 38)

Minor: the Environmental and Safety Program (15 credits)

AWARDS

Undergraduate Fellowship **1997 -2000**
Taiwan Water Supply Corporation Scholarship for Outstanding Student, Taichung, Taiwan.

Graduate Fellowship **2001**
Taiwan Water Supply Corporation Scholarship for Outstanding Student, Taichung, Taiwan, 2001

TEACHING EXPERIENCE

University of Maryland-College Park, MD 20742
Teaching assistant – Biomedical Instrumentation **2007 Fall**
Assisted students in completing their projects, and graded all software homework

Teaching assistant –Probability and Statistics **2001 Spring /Fall**
Core courses at Department of Atomic Science, NTHU, Hsinchu, Taiwan R.O.C.
graded all written homework and exam

PROFESSIONAL EXPERIENCE

Center for Environmental Safety & Health Technology Development, Industrial Technology Research Institute, Hsinchu, Taiwan 300, R.O.C
Associate researcher **2004-2005**

PUBLICATIONS AND PAPERS

Peer reviewed journal articles:
Doong, R. A. and **Lai, Y. J.** (2005) Dechlorination of tetrachloroethylene by palladized iron in the presence of humic acid. Wat. Res. (39) 2309-2318.
Doong, R. A and **Lai, Y. J.** (2006) Effect of metal ions and humic acid on the dechlorination of tetrachloroethylene by zerovalent iron. *Chemosphere.* (64). 371-378.

Summer Fellowship: Investigating the Fate and Persistence of dichloroacetamide herbacide safeners in model environmental systems

Basic Information

Title:	Summer Fellowship: Investigating the Fate and Persistence of dichloroacetamide herbacide safeners in model environmental systems
Project Number:	2008MD176B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	MD-7
Research Category:	Engineering
Focus Category:	Toxic Substances, Non Point Pollution, None
Descriptors:	None
Principal Investigators:	Allen Davis

Publication

Maryland Water Resources Research Center Summer Fellowship 2008

Research Summary

John D. Sivey

Department of Geography and Environmental Engineering, Johns Hopkins University, Baltimore, MD

Project Title: Investigating the fate and persistence of dichloroacetamide herbicide safeners in model environmental systems

Research Advisor: Prof. A. Lynn Roberts

Introduction

The scientific literature is virtually silent regarding the environmental chemistry, occurrence and overall fate of herbicide "safeners". These widely used agrochemicals, also known as herbicide antidotes, are used to protect crop plants from the deleterious effects of herbicides.[1, 2] But, *are safeners safe*? Herbicide safeners and their degradates likely represent a "new" class of emerging contaminants in aqueous systems (including drinking water sources) proximate to agricultural lands. The structures of two popular dichloroacetamide safeners (benoxacor and dichlormid) are shown in Figure 1, along with several observed transformation products. U.S. dichloroacetamide safener use can be conservatively estimated to exceed 20 million lb/yr, with over 125,000 lbs applied annually in Maryland.[3] Under reducing conditions, dichloroacetamide safeners could be transformed to monochlorinated species, which are likely to be more potent alkylating agents (i.e., mutagens) than the parent structures.[4, 5] As such, *safener degradation products may be of greater toxicological concern than the parent compounds*. The purpose of this work is to systematically evaluate the persistence and abiotic reactivity of the dichloroacetamide safeners and their degradation products formed in model aqueous systems under iron-reducing conditions.

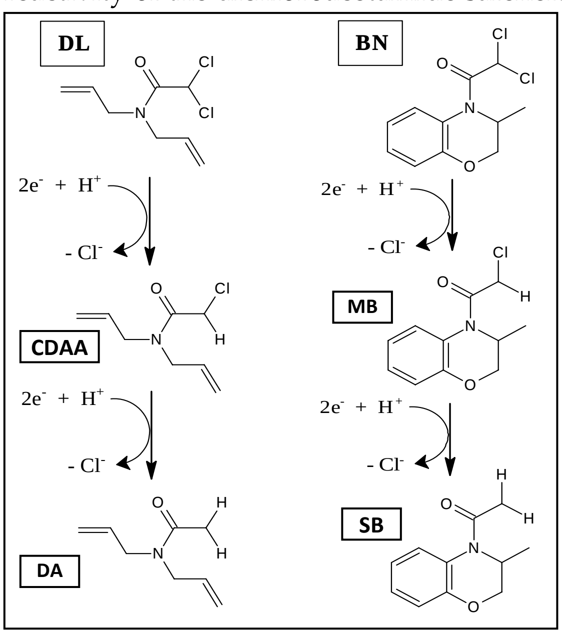

Figure 1. Reduction pathways of dichlormid (DL) and benoxacor (BN) observed in the presence of Fe(II) and ferric oxides (goethite and hematite) in our laboratories. The hydrogenolysis products of DL are CDAA and N,N-diallylacetamide (DA). The products of BN are mono-chlorobenoxacor (MB) and deschloro-benoxacor (SB).

Experimental Design

Objective: *Determine the rates and products of chloroacetamide safener reactions with Fe(II) in the presence of iron oxides*: Goethite, one of most abundant iron oxides in soils,[6] was used as a template for reduction reactions involving two safeners (dichlormid and benoxacor) and adsorbed Fe(II). Iron oxide-associated Fe(II) has been shown to be a viable reductant of many organic contaminants.[7] Reactors contained an iron oxide and Fe(II), both added as aqueous spikes, with pH fixed with MOPS buffer. Reactions were initiated by spiking with a safener delivered in methanol; final methanol concentrations in reactors were ≤ 0.2% v:v. Three sets of control experiments were performed: (*i*) buffer only, (*ii*) buffer and iron oxide only, and (*iii*) buffer and Fe(II) only. Reactors were prepared and incubated (with continuous mixing) in an anaerobic glove bag at 21±1°C. Periodically, samples were filtered (0.2 μm nylon syringe filter) and extracted into toluene. Toluene extracts were analyzed by gas chromatography/mass spectrometry (GC/MS) to quantify the loss of parent compounds and the formation of transformation products.

Results and Discussion

Dichlormid and benoxacor are unreactive in control experiments with iron oxides in the absence of Fe(II) and with Fe(II) in the absence of iron oxides. Hydrolysis of dichlormid and benoxacor is slow at environmentally relevant pH values (4.0 – 9.0); at near-neutral pH, hydrolysis half-lives exceed 575 d (data not shown).

Preliminary investigations of benoxacor and dichlormid reactivity with dissolved Fe(II) indicate no parent compound loss after five days at pH 7.0. Similar recalcitrance was observed in systems containing safeners in the presence of goethite (no Fe(II) added). However, reductive transformations of benoxacor and dichlormid were observed in reactors containing both Fe(II) and goethite. A time course for the reaction of benoxacor with Fe(II) and goethite is shown in Figure 2. The results indicate that benoxacor undergoes sequential hydrogenolysis steps, generating monochlorobenoxacor and, in turn, deschlorobenoxacor. Mass balance calculations indicate that the observed dechlorination products account for essentially all of the initial benoxacor concentration.

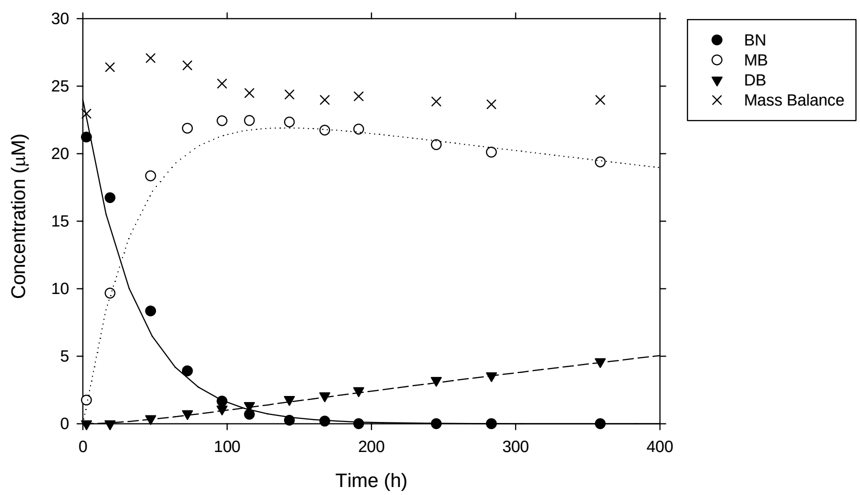

Figure 2. Reaction time course of benoxacor (BN) with goethite (7.2 g/L = 345 m^2/L) and Fe(II) (3 mM) in MOPS buffer (8 mM) with a final pH of 6.61. The sequential hydrogenolysis products of benoxacor (monochlorobenoxacor (MB) and deschlorobenoxacor (DB)) were quantified using synthesized reference materials. Lines represent model fits from *Scientist* 3.0, assuming the following reaction pathway and stoichiometry: BN → MB → DB.

The reaction of dichlormid with Fe(II) and goethite proved to be more complex than that of benoxacor. In addition to the expected hydrogenolysis product of dichlormid (namely, CDAA), two additional products (W and X) were shown to form in parallel with CDAA (Figure 3). Analysis of GC/MS data provides the following insights into the structure of Products W and X: (i) Like CDAA, the molecular weights of Products W and X equal 173 g/mol; (ii) Isotope patterns for Products W and X indicate that both have a single Cl atom; (iii) Fragmentation patterns suggest that, relative to CDAA, W and X lack the following functionalities: $-CH_2CH=CH_2$, $-CH=CH_2$, and $-CClH_2$. The reaction pathways summarized in Figure 4 depict four possible products (**I - IV**, each with MW = 173 g/mol) that can be formed in parallel to CDAA following electron transfer to dichlormid. Based on cyclization efficiency and radical stabilization arguments, **I** (formed via two 6-member ring closures and two secondary radicals) is expected to be generated the most rapidly, followed by **II** (formed via a 6- and 5-membered ring closure and a 1^{o} and 2^{o} radical). This suggests that Product X (the most abundant of the unknown products) likely corresponds to **I**, and Product W likely corresponds to **II**.

These results suggest that the presence of N-allyl groups may significantly alter the fate of chloroacetamides in reducing environments. Our findings indicate that the reduction products of chloroacetamide safeners are more recalcitrant to further abiotic reduction than the parent compounds. The human and ecotoxicological effects of the observed safener reduction products—most notably the cyclization products of dichlormid—are, at best, poorly understood.

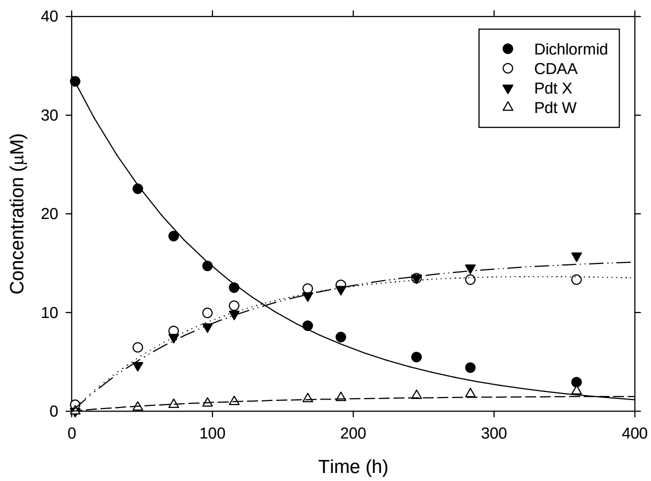

Figure 3. Time course for the reaction of dichlormid with Fe(II) (3 mM) in the presence of goethite (345 m^2/L) at pH 6.6 controlled by MOPS buffer (8 mM). Lines represent model fits from *Scientist* 3.0, assuming products are formed in parallel.

Overall, our results indicate that abiotic reactions with goethite-associated Fe(II) can transform chloroacetamide safeners on environmentally relevant time scales (~ days) via reductive dechlorination reactions. These reactions may affect the fate of chloroacetamide safeners in redox transition zones where Fe(II) concentrations are elevated, especially in iron-reducing environments such as saturated soils and sediments. In addition, the identification of hydrogenolysis and (in the case of dichlormid) cyclization products of safeners described herein may facilitate future occurrence studies of safeners and their environmental transformation products.

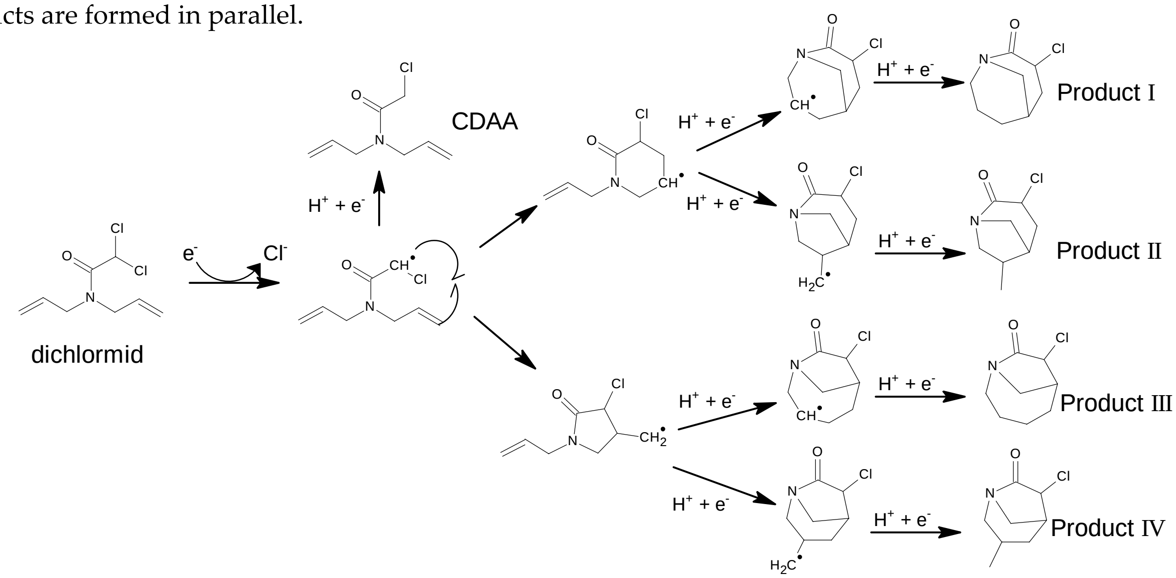

Figure 4. Possible mechanisms for the reaction of dichlormid with Fe(II) and goethite.

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(2) Chesters, S.; Simsiman, G. V.; Levy, J.; Alhajjar, B. J.; Fathulla, R. N.; Harkin, J. M. Environmental fate of alachlor and metolachlor. *Rev. Environ. Contam. Toxicol.* **1989,** *110*, 1-74.

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(4) Jablonkai, I. Alkylating reactivity and herbicidal activity of chloroacetamides. *Pest Manag. Sci.* **2003,** *59*, 443.

(5) Klaassen, C. D.; Watkins, J. B., III (Eds). *Casarett & Doull's Essentials of Toxicology;* McGraw-Hill: New York: 2003; p 533.

(6) LaKind, J. S.; Stone, A. T. Reductive dissolution of goethite by phenolic reductants. *Geochim. Cosmochim. Acta* **1989,** *53*, 961-971.

(7) Klausen, J.; Trober, S. P.; Haderlein, S. B.; Schwarzenbach, R. P. Reduction of substituted nitrobenzenes by Fe(II) in aqueous mineral suspensions. *Environ. Sci. Technol.* **1995**, *29*, 2396-2404.

Basic Information

Title:	
Project Number:	2008MD204B
Start Date:	3/1/2007
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	MD05
Research Category:	Not Applicable
Focus Category:	, None, None
Descriptors:	
Principal Investigators:	

Publication

Deleted Project

Information Transfer Program Introduction

For the seventh year, the Maryland Water Resources Research Center supported a 1-day symposium on a water issue important to the State.

How Can Maryland Agriculture and the Bay Coexist?

Basic Information

Title:	How Can Maryland Agriculture and the Bay Coexist?
Project Number:	2008MD181B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	MD-5
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Allen Davis, Philip Kearney

Publication

How Can Maryland Agriculture and the Bay Coexist?

The Maryland Water Resources Research Center sponsored a 1-day colloquium on *How Can Maryland Agriculture and the Bay Coexist?* on October 31, 2008. This event consisted of a series of seven presentations and related discussion. Topics and speakers included:

- ***"Maryland's Agricultural Ecosystem, Yesterday, Today and Tomorrow."*** Robert Kratochvil, Plant Science & Landscape Architecture, University of Maryland.
- ***"Managing Phosphorus on the Farm."*** Frank J. Coale, Environmental Science & Technology, University of Maryland.
- ***"Adaptive Nitrogen Management for Improving Water Quality: Challenges and Opportunities."*** Jack Meissinger, Environmental Management & Byproducts, ARS USDA, Beltsville, MD.
- ***"NAWQA has Provided a Wealth of Information on Pesticides & Nutrient Movement."*** Judith Denver, Hydrologist/Study Unit Chief, USGS Dover, Delaware.
- ***"Nutrient Management in Maryland: A Recent History."*** Patrica Steinhilber, Agricultural Management Program, University of Maryland.
- ***"The Water Quality Improvement Act of 1998 – 10 Years Hence."*** Royden Powell, Assistant Secretary, Conservation, Maryland Department of Agriculture.
- ***"Agricultural Policies for Restoring the Bay: Successes and Failure."*** Russell Brinsfield, Wye Research and Education Center, Queenstown, MD.

Attendance included over 100 faculty, students, and professionals from outside agencies. The Maryland Sea Grant College and the College of Agriculture and Natural Resources co-sponsored this event.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	4	0	0	5
Masters	4	7	0	0	11
Ph.D.	3	0	0	2	5
Post-Doc.	0	0	0	1	1
Total	8	11	0	3	22

Notable Awards and Achievements

A discussion with a Maryland scientist was published in a Baltimore Sun Blog. The research was supported by Maryland Water Resources Research Center 104B funds.

March 3, 2009 Icy dilemma: Road salt taints streams, reservoirs

Ever wonder what happens to all that rock salt that gets sprinkled on roads and highways, walks and driveways when the snow falls? It winds up in area streams, ponds and lakes, where research indicates it's altering the development of frogs and other aquatic life.

Salt levels in streams tend to spike after a storm like the one that hit Maryland and the rest of the East Coast this week. While those peaks do drop within hours or days, the salt washed downstream seems to be building up in some ponds and lakes.

The salt concentrations in Baltimore's drinking water reservoirs have been slowly rising. A report several years ago found that levels in Liberty had tripled since the 1970s, and quadrupled in Loch Raven, trends that officials attribute to the increased use of salt to de-ice growing amounts of pavement around the region. Still the treated water supplied by the city remains below the salt threshold recommended by the federal government, says city spokesman Kurt Kocher.

So the water's not too salty to drink, but it may not be quite so kopacetic for the critters that spend their lives immersed in it. Chris Swan, an assistant environmental science professor at the University of Maryland, Baltimore County, found that the slight elevation in salt seen in area waters is enough to alter the development of grey tree frogs - like the ones that visit my backyard every spring. They grow faster and larger than normal, he says. Some insects found in area streams and ponds also thrive in salty water.

But Swan found even modest amounts of salt are bad for zooplankton, the microscopic animals swimming in water that feed on algae, and upon which some fish feed. Likewise for some of the microbes that help regulate the nutrients in the water.

The long-term effects of this gradual dosing of our freshwater environment are unknown. Kocher, a spokesman for the Baltimore Department of Public Works, said city officials are keeping an eye on the salt levels in our drinking water, but have no plans to stop using the stuff to maintain safe streets.

"It's not something that anyone wants to have, but we do have to balance that against a car going off the road," he said.

Likewise, State Highway Administration spokesman Dave Buck says road crews try to scatter only as much salt on the pavement as they need to to ensure safe driving. Trucks are equipped with special spreaders to distribute it evenly and minimize waste, he said. The state puts down 200,000 or more tons of the stuff every winter, though - with tens of thousands of tons sprinkled in the past few days alone.

(The truck pictured above, photographed by the Baltimore Sun's Amy Davis, was working for the city schools, treating an alley near Margaret Brent Elementary School in Charles Village.)

"I'm not going to suggest we should sacrifice human safety for frogs," Swan says, "but we ought to figure out if there are better ways to manage it.

Publications from Prior Years

1. 2005MD89B ("Chemical and Biological Availability of Zinc in Road Runoff Entering Stormwater Retention Ponds") - Articles in Refereed Scientific Journals - “Impacts of Weathered Tire Debris on the Development of Rana Sylvatica Larvae” K.M Camponelli, R.E Casey, J.W Snodgrass, S.M Lev & E.R Lenda Chemosphere, 74, 717-722 (2009)