Virginia Water Resources Research Center
Annual Technical Report
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Introduction

The Virginia Water Resources Research Center (VWRRC) was established at Virginia Tech in 1965 as a federally authorized program. In 1982, the Virginia General Assembly authorized the VWRRC as a state agency under the Code of Virginia (§23-135.7:8).

Mission

The VWRRC promotes research on practical solutions to water resources problems; provides research and educational opportunities to future water scientists; and facilitates timely transfer of water resources information to policy- and decision-makers and the general public.

Mission Elements

Research

1. Assisting university researchers in securing research support from public and private sources to address water resources issues;
2. Assisting university researchers in initiating and executing water resources research;
3. Conducting research on water resources issues appropriate for expertise of personnel affiliated with the VWRRC.

Education

Advancing educational opportunities for students in water resources fields by

1. Helping university researchers provide undergraduate and graduate research experiences in water resources;
2. Coordinating an undergraduate minor and graduate certificate in water resources at Virginia Tech.

Outreach

1. Maintaining and frequently updating the VWRRC website and social media outlets to provide access to information on water resources science, engineering, and policy.
2. Publishing *Virginia Water Central,* a newsletter featuring articles on water-related policy and law, summaries of water conditions in Virginia, and news briefs about water issues.
3. Producing *Virginia Water Radio,* a weekly radio show and podcast featuring unique perspectives on water sounds and news, and information involving Virginia's waters.
4. Securing research expertise to work in an advisory capacity with public and private sectors, as requested.
5. Initiating and participating in development and execution of conferences and symposia on Virginia, regional, and national water issues.

Program Administration

Administrative oversight of the VWRRC is provided by the Dean of the College of Natural Resources and Environment. A Statewide Advisory Board appointed by the Governor advises the VWRRC Director on state water research and information priorities. Because of its multiple legislative authorities and administrative responsibilities, the VWRRC has a number of reporting obligations. In addition to the annual reporting requirements to the USGS and the National Institutes for Water Resources (NIWR), it presents an annual report to the Virginia Tech administration and the College of Natural Resources and Environment. Five-year reports and reviews are presented to the USGS and the State Council on Higher Education for Virginia (SCHEV).

National Affiliations

The VWRRC is affiliated with NIWR and the Universities Council on Water Resources (UCOWR).

Programs of the VWRRC

Programs are structured to meet strategic goals of the VWRRC and are consistent with the VWRRC mission as authorized by the U.S. Congress through the Water Resources Research Act of 1984 (Public Law 98-242), and Code of Virginia (§23-135.7:8). Programs in research and education are available to students and faculty at all Virginia colleges and universities. Outreach and collaborative programs include information transfer to policy/decision makers and citizens, and collaborative partnerships with state and federal agencies and other water-interest groups.

A. Research Programs

1. The VWRRC's statewide competitive grants program provides research funds to find practical solutions to water problems in Virginia and the region. The grant period begins July 1 and ends June 30 of the following year. The review criteria include (a) technical merit of the proposed project, (b) relevance to Virginia and the region, (c) relevance to contemporary water issues, and (d) ability to provide research opportunities for graduate and undergraduate students. A priority listing of water research needs for this competitive grants program is updated annually in consultation with the VWRRC's State Advisory Board. These grants are designed to support research efforts with a high potential for expanded funding from additional sources.
2. The VWRRC applies for external grants and conducts in-house research.
3. The VWRRC facilitates research team building and interdisciplinary, multi-institute collaborative research.
4. The VWRRC facilitates research opportunities to other university faculty and external contractors through a partnership with federal agencies that provides targeted funding from the USGS.

B. Educational Programs

1. The VWRRC provides research opportunities to undergraduate students and research assistantships to graduate students who participate in sponsored research. Also, numerous graduate and undergraduate students are supported through the VWRRC's competitive grants program in Virginia Tech academic departments, and at Virginia's other colleges and universities.
2. In 1999, the VWRRC established the William R. Walker Graduate Research Fellowship to honor the many contributions of Dr. William R. Walker, the VWRRC's first director. The annual monetary award is intended for individuals preparing for a professional career in water resources and is provided to at least one graduate student at Virginia Tech each year. Details of the program can be found on the VWRRC website http://www.vwrrc.vt.edu/walker_fellowship.html.
3. The VWRRC coordinates the interdisciplinary Watershed Management Undergraduate Minor and a Watershed Management Graduate Certificate Program in collaboration with five colleges and ten departments at Virginia Tech.
4. The VWRRC supports and advises the Virginia Tech Chapter of the American Water Resources Association.

C. Outreach and Collaborative Programs

1. The VWRRC provides administrative support for the Virginia Water Monitoring Council.
2. The VWRRC publishes research reports and symposia proceedings.
3. The VWRRC publishes a quarterly newsletter, *Virginia Water Central.* It features scientific and educational articles, legislative information, and water news of interest. The newsletter is available to the public at http://www.vwrrc.vt.edu/watercentral.html and electronic copies are provided via email to more than 680 subscribers.
4. The VWRRC sponsors or co-sponsors symposia, workshops, and seminars addressing contemporary water resources issues.
5. The VWRRC facilitates peer reviews for state programs when requested.
6. The VWRRC website (http://www.vwrrc.vt.edu) serves as a repository of the Center's publications, houses an academic expert database, provides updated news and information relevant to water resources, and manages website links for several collaborative partners, including the Virginia Water Monitoring Council, the Virginia Department of Conservation and Recreation Stormwater BMP Clearinghouse, and the Clinch Powell Clean Rivers Initiative.
7. The VWRRC has Twitter and Facebook sites to facilitate information exchange related to water resources and related news at the VWRRC.

Research Program Introduction

The research program of the Virginia Water Resources Research Center (VWRRC) is supported through

- its annual appropriation from the Commonwealth of Virginia,
- external funding through grants and contracts, and
- a portion of overhead generated by external funding.

The VWRRC's 104(b) funds are not allocated to support research, but are used to support its outreach and information dissemination programs, and to provide administrative support.

The VWRRC funded four new research projects from the Center's state budget through allocation of $5,000 seed grants to graduate students at Virginia Tech in the Departments of Civil and Environmental Engineering, Biological Systems Engineering, and Geosciences. In addition, four research projects that passed through the USGS and were administered by the VWRRC were active during the reporting period. Basic information regarding these four pass-through grants and resulting products are described in the following section.

Denitrifying bacterial community structure and diversity, and denitrification potential as affected by hydrologic design and soil properties in wetlands created in Chesapeake Piedmont, USA

Basic Information

Title:	Denitrifying bacterial community structure and diversity, and denitrification potential as affected by hydrologic design and soil properties in wetlands created in Chesapeake Piedmont, USA
Project Number:	2010VA142G
Start Date:	9/1/2010
End Date:	8/31/2012
Funding Source:	104G
Congressional District:	VA-11
Research Category:	Water Quality
Focus Category:	Wetlands, Water Quality, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	Changwoo Ahn

Publications

1. No publication available at this time.
2. No publication available at this time.
3. Peralta, R., C. Ahn, M. Voytek, J. Kirshtein. 2013. Bacterial community structure of *nirK*-bearing denitrifiers and the development of soil properties in created mitigation wetlands. *Applied Soil Ecology*. 70: 70-77
4. Ahn, C., R. Peralta. 2012. Soil condition properties are useful in examining denitrification function development in created mitigation wetlands. *Ecological Engineering*. 49: 130-136

Soil properties are useful to examine denitrification function development in created mitigation wetlands

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Abstract

We investigated structural soil attributes, the development of denitrification potential (DP), and their relations in created and natural non-tidal freshwater wetlands in Virginia. Soil attributes included soil organic matter (SOM), total organic carbon (TOC), total nitrogen (TN), pH, gravimetric soil moisture (GSM), and bulk density (D_b). A subset of soil attributes were analyzed across the sites, using euclidean cluster analysis, resulting in three soil condition (SC) groups of increasing wetland soil development (i.e., SC1<SC2<SC3 less to more developed) as measured by accumulation of TOC and TN, the increase of GSM, and the decrease of D_b. Denitrification enzyme activity (DEA) was measured for DP. DEA rates were somewhat different by wetland site, but with no age-based trajectory. No significant difference was seen in DEA rates by sampling period ($p = 0.06$). However, DEA rates were clearly differentiated by SC groups, with the highest rates in SC3 followed by SC1 and lowest in SC2. The lowest DEA rates in SC2 seemed associated with a higher soil pH (~6.6) in the group than that (~5.3) of the other SC groups, but it needs a further investigation. The principal component analysis (PCA) of soil physicochemical properties and average DP showed the association between the

development of denitrification function and the maturation of soil conditions in wetlands. The outcome of the study suggests that the use of a suite of simple soil properties may be useful to examine the development of denitrification function in created mitigation wetlands. The inclusion of soil properties in post-construction monitoring should be required to enhance our understanding and prediction of the functional development of created mitigation wetlands.

Keywords: wetland soils, denitrification potential, DEA, soil condition (SC), created mitigation wetlands, functional development

INTRODUCTION

Denitrification is one of the key ecological functions of natural wetlands extensively studied (Groffman, 1994; Hunter and Faulkner, 2001; Hill and Cardaci, 2004). Denitrification requires anoxic conditions and organic matter that are often associated with hydric soils characteristic of most natural wetlands (Mitsch and Gosselink, 2000). Numerous studies have investigated the factors controlling denitrification in an attempt to better understand the process, mostly focusing on the roles of NO_3^- availability, O_2, and pH (Firestone et al., 1979, Weier et al, 1993; Thomas et al., 1994).

Denitrification is difficult to quantify due to its high spatial and temporal variability and because the N_2 produced by denitrification is difficult to measure in the presence of ambient concentrations of atmospheric N_2 (Tiedje et al., 1989). Denitrification can be assessed with surrogate measurements such as denitrification potential (DP). Denitrification enzyme activity

(DEA) has been used as an index of DP in numerous studies (Groffman et al., 1994; Jordan et al., 2007; Hopfensperger et al., 2009). The DEA represents the activity of denitrifying enzymes *in situ* (i.e., enzymes active at the time of sampling), and therefore is indicative of the historic site conditions (Tiedje et al., 1989). The rate represents not only enzyme activity, but also the environmental factors that control enzyme expression (O_2 content, C availability, and NO_3^- concentration). In anaerobic environments without carbon limitations, the amount of enzyme produced is proportional to the concentration of nitrate available, and the rate of N_2O production is proportional to the enzyme content (Tiedje et al., 1989). The DEA is useful for site comparisons since it offers a method by which the DP can be compared across different soil types and conditions (Groffman et al., 1994, Jordan et al., 2007). In addition, studies have also showed that DEA may be useful in estimating field denitrification rates (Groffman and Tiedje, 1989; Hopfensperger et al., 2009).

With increasing age and additional plant growing seasons, the soil properties of a created wetland should mature and develop, which is critical in both structural and functional ecosystem development of mitigation wetlands created and/or restored. Previously, many mitigation projects have been generally unsuccessful in meeting the performance criteria that have been legally mandated (e.g., vegetation community development) (National Research Council 2001). Moreover, even successful cases of mitigation wetlands often fail or turn out to be slow in developing soil properties that are critical for the development of more complex functional attributes of wetlands (Wolf et al., 2011). An excellent indicator of soil development and quality is soil organic matter (SOM) (Howard and Howard, 1993; Schaffer and Ernst, 1999; Bruland and Richardson 2005), as it is a major source of nutrients (especially N) (Sollins et al., 1999), except in peat-accumulating soils. SOM provides both organic N, the substrate of mineralization, and organic carbon (OC), which is a required energy source of both mineralizing and heterotrophic denitrifying microbes (Beauchamp at al., 1989; Groffman, 1994; Hill and Cardaci, 2004). The greater accumulation of OC may increase denitrification rates.

Dee and Ahn (2012) found that soil condition (SC) attributes such as SOM, bulk density (D_b), and gravimetric soil moisture (GSM), all related to the maturation of a created wetland, were significantly associated with the development of structural and functional vegetation attributes in created mitigation wetlands. The study also reported that soil properties varied greatly within sites than between sites in a spatially heterogeneous manner, suggesting that site age does not necessarily equate with the overall maturity of mitigation wetland. Soil properties are interdependent with higher SOM or soil organic carbon (SOC) displacing compacted soil and reducing D_b, in addition to providing an absorptive substrate for water retention, thus increasing soil moisture (Ballantine and Schneider 2009, Bruland and Richardson 2005, Ehrenfeld and others 2005, Reddy and DeLaune 2008). Little, however, is known whether and how SCs are associated with the development of a biogeochemical function (i.e., denitrification) critical to water quality ecosystem services provided by wetlands.

We studied soil properties and DEA rates in both created mitigation and natural wetlands, all located in the Virginia piedmont. The objective of this study was to investigate if soil properties (i.e., SC groups) were associated with a functional property (i.e., DEA rates). The inclusion and use of soil properties in post-construction monitoring and management may be useful to track the functional maturity of created mitigation wetlands.

METHODS

Site descriptions

Five non-tidal freshwater wetlands located in the Piedmont physiographic region of northern Virginia were chosen for this study (mean annual precipitation 109 cm, mean temperature min 7 ºC/ max 18ºC) (see Wolf et al., 2011). Three of the wetlands were mitigation wetlands created by Wetland Studies and Solutions Inc. (WSSI) on old farmland with a predominantly herbaceous cover with little difference (Dee and Ahn, 2012). The other two were natural wetlands and include bottomland riparian forested wetlands and open herbaceous wetlands.

All created wetlands contain at least a 0.3 m low permeability subsoil layer covered with the original topsoil from the site that was supplemented with commercially available topsoil to a depth of 0.2 m. This design creates a perched, precipitation-driven water table close to the soil surface and limits groundwater exchange in the wetland. Loudoun County Mitigation Bank (LC) is a 12.9 ha wetland and upland buffer complex, constructed in the summer of 2006 in Loudoun County, Virginia (39º1′ N, 77º36′ W). LC receives surface water runoff from an upland housing development and forested buffer, as well as minor groundwater inputs from toe-slope intercept seepage. LC consists of two wetland basins (LCs 1 and 2). LCs 1 and 2 are two contiguous sites separated by a berm and connected by a drainage channel with LC1 approximately 0.4 m higher in elevation than LC2. This design causes LC1 to drain more quickly leaving it inundated for shorter periods after precipitation than LC2, while LC2 can remain under standing water (e.g., < ~12 cm) for longer periods. Bull Run Mitigation Bank (BR) is a 20.2 ha wetland and upland buffer complex, constructed in 2002 in Prince William County, Virginia (38º51′ N, 77º32′ W). The site may receive water from Bull Run from a culvert structure that routes water via a central ditch through the wetland, as well as overbank flow from Bull Run, which sharply bends around the corner of the site. The wetland receives limited surface water runoff from wetlands and negligible groundwater. North Fork Wetlands Bank (NF) is a 50.6 ha wetland, constructed by WSSI in 1999 (10 years old during study year) in Prince William County, Virginia (38º49′ N, 77º40′ W). With the exception of minor contributions from toe-slope intercept seepage, the site is disconnected from the groundwater by an underlying clay liner. Study plots are located in two created hydrologic regimes: main pod area – fed by upland surface water runoff and a tributary of the North Fork of Broad Run that is controlled by an artificial dam; and vernal pool area – located in the southwest quadrant of the wetland and fed solely by precipitation.

Manassas National Battlefield Park (BFP), established in 1940, is a 2,000 ha site with areas of natural wetland coverage located in Prince William County, Virginia (38º49′ N, 77º30′ W). An area of herbaceous wetland within a matrix of forested floodplain was selected for study and comparison to the created wetlands. The site is connected to Bull Run by a culvert on its eastern end and also receives groundwater and upland surface water runoff. Vegetation is mostly herbaceous with a few mature trees interspersed throughout. Banshee Reeks Nature Preserve (BSR), established 1999, is a 290 ha site with areas of seep and riparian wetlands located in Loudoun County, Virginia (39º1′ N, 77º35′ W). These floodplain riparian wetlands receive water from groundwater springs, surface water runoff, and occasional overbank flooding from Goose Creek. Vegetation is mature bottomland forest with little understory.

Soil sampling

Soil samples for this study were collected in October and December 2010 and April and June 2011, totaling four times. A total of 16 study plots in the created wetlands (e.g., LC1, LC2, BR and NF) and 4 plots in the natural wetlands (e.g., BN and BP) were selected. Each plot was 100 m^2 (10 x 10 m) and was divided into four 5 x 5 m quadrants. Within each quadrant, three soil samples were taken at random at the depth of 5-10 (targeting at 7.5 cm) cm from the top using an auger (1 1/4" diameter) and combined in a polyethylene bag. Soils were mostly saturated with little standing water (< 2 cm). All samples were kept in a cooler with ice packs to slow bacterial activity until further processing in the laboratory. At the laboratory, each bag was homogenized manually to mix all three samples for each quadrant. Any visible root or plant material was removed prior to homogenization.

Soil physicochemical analyses

To determine SOM, total organic carbon (TOC), total nitrogen (TN) and pH, soils were air dried. Once air dried, soils were macerated using a mortar and pestle and large constituents (e.g. rocks and large organic debris) were removed. A Perkin-Elmer 2400 Series II CHNS/O Analyzer (Perkin-Elmer Corporation, Norwalk, CT, USA) was used to analyze TOC (~TC) and percent TN. Sub-samples (2-3 grams of air dried soil) were separated for SOM, loss on ignition (LOI) method, and oven dried at 105 ◦C for 24 hours, weighed and placed at 405 ºC for 16 hours. SOM (%) was measured using weight loss on ignition method (Wilson and Sanders, 1996). For gravimetric soil moisture (GSM), field-wet mass was measured and samples dried at 105 ºC for 48 hours. GSM was calculated by the difference between field moist mass and oven dried mass [(wet mass – dry mass)/ (dry mass) x 100] (Gardner, 1986). For pH determination, 10 g air dried soil samples were combined with 10 mL of deionized water, swirled and left to stabilize for 10 minutes prior to measurement (Thomas, 1986). Bulk density (D_b) was determined for each core, first weighing the entire field-moist core, converting to dry weight based on GSM percentage, and dividing by the total volume of the soil in the core (200.2 cm^3). Soil temperatures were measured using ibuttons (Embedded Data Systems Inc.) for each sampling periods, including a week before and after the period. The ibuttons are computer chips that contain temperature sensors and are encased in portable button sized capsules. All ibuttons were buried at each plot at a soil depth of 5 to 10 cm.

Denitrification Potential (DP)

The potential rate of the initial denitrification phase was quantified using the denitrification enzyme activity (DEA) assay with the acetylene block technique modified from Smith and Tiedje (1979) and Groffman et al. (1999). Field moist soil samples for each quadrant were homogenized after collection and kept refrigerated until DEA assay. Replicate assays were performed per quadrant in 125 mL Erlenmeyer flasks with airtight stoppers (Thermo Fisher Scientific) containing 25 mL of DEA media (1 mM glucose, 1 mM KNO_3 and 1g per L chloramphenicol) and 25 g of soil. The resultant soil slurries were bubbled with N_2 gas for 11 min (including 1 min headspace flush), sealed with airtight septa centered stoppers, purged with N_2 for 1 min, vacuumed for another 1 min, pressurized with N_2 and vented prior to addition of 10 mL of scrubbed acetylene (Hyman and Arp, 1987). To ensure equal distribution of acetylene and N_2O, flasks were placed on a rotary shaker table at 125 rpm and samples were taken at 30 and 90 min. Gas samples were stored in 2 mL airtight Monojet vials and kept in a cool dry place until analyzed using a Shimadzu GC-8a ^{63}Ni electron capture detector gas chromatograph (Shimadzu Corporation, Columbia, MD, USA) equipped with a Hayesep Q, 80/100- mesh column (320C injector/detector temperature, 80ºC oven temperature and 300 kPa carrier gas flow). Standards ranging from 0.229 to 4293.75 µg N_2O-N/L were generated from 1% N_2O in

N_2 balance (Air Liquide, Houston, TX, USA). Denitrification rates were calculated using the difference between N_2O concentrations at the two sampling times based on calibration curves.

Statistical Analyses

SC groups were determined by cluster analysis at 70% similarity of soil physicochemical parameters that included pH, GSM, Db, TOC and TN of at all four sampling periods. Statistical significance of the SC groups was verified by applying a similarity profile test (SIMPROF) which performs permutation tests at each node of the cluster analysis dendogram. SIMPROF thus determines whether each cluster set has significant evidence of a multivariate pattern different from the rest (Clarke and Gorley 2006). DEA rates were below our detection limit for the month of October 2010 at all sampling plots. Further discussion of DEA rates and relationship to soil properties was thus limited to the samplings conducted in the other three sampling periods. PCA was used to visualize 'best fit' of plots along soil physicochemical properties, and DEA rates. All test described thus far were performed using PRIMER 6, version 6.1.5 (Primer-E Ltd., Plymouth, United Kingdom). Analysis of variance (ANOVA) was used to compare soil physicochemical variables and DP between soil condition groups. *Bonferroni* pairwise t-tests for uneven variances were carried out for each ANOVA to determine between-group differences. Spearman rank correlations were performed between soil physicochemical attributes and DP to determine significant relationships between factors. ANOVAs and correlations were all conducted using SYSTAT 12 (Cranes Software International Ltd).

RESULTS

Soil properties and DEA rates by wetland site

We did not observe an age-related maturation of soils in the study sites. Soils from the forested natural wetland and one of the youngest created wetlands (e.g. BN and LC1) contained the highest TOC (1.9 to 2.1 %) and TN (0.18 to .20 %). NF, the 11-year old created wetland, contained SOM comparable to LC1 and BN, which ranged between 4.4 and 5.3 % (Table 1). Two of the younger created wetlands (e.g. LC2, BR) and the natural wetland (e.g. BP) had the lowest SOM (2.8 to 3.2 %), TOC (0.9 to 1.2 %) and TN (0.08 to .11 %) (Table 1). Soil pH was significantly higher in NF (6.5) and lower (4.3) in BP (Table 1). Soil pH in the rest of the wetlands (e.g. LC1, LC2, BR and BN) ranged from 5.1 to 5.6, with no significant differences between these sites (Table 1). GSM was expectedly higher in the three wetlands with the highest SOM content. BN had the highest mean GSM (43 %) followed by NF (39 %) and LC1 (34 %). There were, however, no significant differences between BN and NF or NF and LC1 (Table 1). DEA rates were highly variable within each site as observed by the high standard error rates, but less so between sites (Table 1). Significantly higher DEA rates were observed in LCs 1 and 2 (228 and 143 µg N-N2O/kg soil/h on average, respectively) than the rest of the sites with the lowest rate observed in the soils of NF (41 µg N-N2O/kg soil/h on average; Table 1).

Soil properties and DEA rates by sampling periods

Differences in SOM, TOC and TN were also found by sampling period (Table 2). SOM, TOC and TN were highest in December, averaging 4.5 %, 1.6 % and 0.14 % respectively (Table 2). The mean soil pH for April and June ranged from 5.7 to 5.8, which was higher than that in December soils (i.e., 5.3 on average) (Table 2). GSM levels were significantly higher in December (40 %), followed sequentially by those in April (35 %) and in June (30 %) (Table 2). Temperature means for the sampling periods in December, April and June were 1.3, 12.8 and 20.5 ºC, respectively, being significantly different, which reflected a natural seasonal variation of soil temperature. However, DEA rates were a little bit higher in summer months (i.e., April and June) than in the winter (December), but not significantly different ($p = 0.06$) (Table 3).

Soil properties and DEA rates by SC groups across the sites

We derived three SC groups from a cluster analysis of five soil physicochemical attributes; TOC, TN, Db, GSM and pH. SC groups showed progressive soil development/maturation (e.g., SC1<SC2<SC3 less to more developed), irrespective of site (Table 3). SC1 soils were characterized by the lower SOM (3.1 %), TOC (1.0 %), TN (0.1 %), GSM (32 %) and higher Db (1.4 g cm^{-3}). The more developed (or matured) soils of SC3 had higher SOM (4.9 %) TOC (1.9 %), TN (0.2 %), GSM (38 %) and lower Db (1.2 g cm^{-3}). SC2 consisted entirely of plots at NF, the oldest created mitigation wetland in the study. SC2 had intermediate soil characteristics between SC1 and SC3, but was characterized distinctively by higher soil pH (6.6 on average) than those in the other SC groups (Table 3). Overall, soil attributes indicative of wetland soil maturity (e.g., higher SOM and GSM, and lower Db) in SC2 were more similar to SC3 (Table 3).

DEA rates were clearly discernible when analyzed by SC group. DEA rates were significantly higher (177 μg N-N2O kg^{-1} soil h^{-1}) in SC3 with highest TOC, TN and lowest Db (Table 3). The DEA rates showed the lowest (32 μg N-N2O kg^{-1} soil h^{-1}) in SC2 which differed significantly for its soil pH than the rest of SC groups. A PCA of all soil physicochemical attributes and DEA rates was conducted to further tease out the association between DEA rates and soil condition variables. Since TOC, TN and SOM were found to be strong covariates (Table 4), we omitted TN and SOM from the PCA. PCA of the data identified two components with eigenvalues greater than 1 (i.e., 2.49 and 1.58), which accounted for over 81 % of the data variability. Explaining 50 % of the variability, PCA component 1 had highest factor loadings for pH (0.503), GSM (0.542), and Db (-0.54). Component 2 accounted for 32 % of the data variability, with highest component loadings for TOC (-0.616) and DEA rate (-0.673) (Figure 1). The both axes clearly separated SC3, the most mature soil condition, from SC1, the least mature one. It also seems that soil pH separates SC2 from SCs 1 and 3 (Figure 1).

Correlations between soil properties and DEA rates

Spearman rank correlations were performed to relate soil properties and DEA rates irrespective of the SC, site or sampling period (Table 4). TOC and TN were found to be covariates ($\rho = 0.90$) and together positively correlated to SOM contents ($\rho > 0.7$). GSM was positively related to SOM ($\rho = 0.57$), TOC ($\rho = 0.42$) and TN ($\rho = 0.45$). Soil pH demonstrated a positive relationship with SOM ($\rho = 0.35$) and GSM ($\rho = 0.27$). DEA rates were not found to be significantly correlated with any of the structural soil properties, but displayed a negative correlation with soil pH ($\rho = -0.26$; Table 4).

DISCUSSION

Use of SC groups in examining the progress of soil development in created wetlands

Although the mitigation of wetland losses by creating wetlands has become a common practice, there continues to be uncertainty in regards to the degree of functional ecosystem development in created wetlands (Bishel-Machung et al., 1996; Stolt et al., 2000; Campbell et al., 2002). In this study we focused on a suite of SC attributes as a potential indicator for the development of a biogeochemical function (i.e., denitrification) in created mitigation wetlands.

Soil provides the structural matrix in which many biogeochemical processes occur. Spatial variability of soil attributes in both created and restored wetlands were found and discussed in previous studies (Bruland and Richardson, 2005; Bruland and Richardson, 2006) where they found relatively lower spatial variability of those in created wetlands compared to natural wetlands. The outcome of the study showed no relationship between site age and soil development, as shown in similarly higher SOM contents of the natural wetland (e.g., BN), the oldest created wetland (e.g., NF) and one of the youngest wetlands (e.g., LC1) (Table 1). SOM is naturally accumulated through autochthonous (e.g. seasonal plant senescence) and allochthonous or allogenic (e.g. sediment brought by flooding or runoff) inputs of organic matter over time, being a good indicator for soil maturation (Wolf et al., 2011). In addition, wetland soils are generally characterized by their high water holding capacity which is largely due to high SOM content (Reddy and DeLaune, 2008).

SC grouping managed to sort out the study plots that were physicochemically similar across wetland sites, with directionality from less to more developed (i.e., SC1<SC2<SC3). This study revealed that a functional attribute (i.e., DEA rate) was highest in SC3 (Table 3) characterized by greater TOC and TN, lower D_b, and higher GSM, all indicative of maturity in wetland ecosystem development (Table 4). SC groups can be viewed as a measure of soil developmental variation within a created wetland, with some groups lagging others and thus maturing at different rates. The finding that SC can be used to examine the development of

biogeochemical functions in created wetlands has potential application for future monitoring, created wetland design, and post-creation refinement.

Soil properties and DEA

Denitrification is a biochemical processes accomplished by the metabolic activity of soil microorganisms under anaerobic conditions. DEA rates represent potential enzyme activity, where O_2 is limited while C and NO_3^- concentrations are non-limiting. Therefore, the rate of N_2O production is proportional to the enzyme content extant within each soil (Tiedje et al., 1989). In our study, DEA rates were negatively associated with soil pH and positively with TOC regardless of the wetland site (Figure. 1). Among the study plots with similar soil pH, DEA rates were higher in soils with higher SOM, TC, TN, GSM and lower Db, indicating a functional development is clearly associated with the development of soil properties (Table 1, Figure 1).

The pH values of the soils collected from the wetlands ranged between 4.3 and 6.5 (Table 1), showing a typical, acidic characteristic of the soils of Virginia Piedmont (Farrel and Ware, 1991). The Piedmont soils can also be described as clay rich, highly weathered, low base saturation soils (Farrel and Ware, 1991). This indicates a preponderance of acidic soils in this physiographic region that has developed over a long period of time through regional land use changes (Sherwood et al., 2010). DEA rates were found to have a negative association with soil pH (Table 4) in this study, but it is not clear how slightly higher soil pH in SC2 led to a significantly lower DEA rates at the group since we did not study the mechanism(s) by which soil pH within the observed range influences or alters DEA. The relationship between pH and denitrification has been extensively researched, with most studies finding higher denitrification rates at circumneutral pH (Wijler and Delwiche, 1954; Van Cleemput and Patrick, 1974; Thomsen et al., 1994). The DEA rates might have been influenced by some other factor or a set of factors that was not measured in this study. SC2 was composed with four study plots at NF, the oldest created wetland, that were fed by a large open water area. The design of NF and its resulting propensity to flooding might have induced more flooded soil conditions as reflected in higher GSM, leading to a reduction in N mineralization, as observed for this site by Wolf et al. (2011), and limiting the availability of NO_3 substrate known to constrain denitrification in freshwater wetlands (Groffman and Tiedje 1988; Martin and Reddy 1997). Simek and Cooper (2002), in a thorough review of the last half century of the relationship between soil pH and denitrification, concluded that soil pH can influence different parts of the denitrification process in different ways. They mentioned that DEA rates can be influenced by soil pH and are less in acidic soils than neutral or slightly alkaline soils, which does not support our results. It would not be proper to generally interpret our DEA rates and their association with soil pH based on Simek and Cooper (2002) since our DEA rates came from soils of which pH were all under 7, being acidic. They cautioned that due to the gap in specific knowledge it is misguided to assume that there is an optimum pH for denitrification. Since the relation between soil pH and potential denitrification as determined by a variety of incubation methods remains unclear, with results being affected both by original conditions in soil samples and by unknown changes during incubation (Simek and Cooper, 2002) a further study for the relationship between soil pH and DEA rates is necessary.

Tracking functional development in post-construction of mitigation wetlands

Time is reasonably considered the master variable in soil development (e.g. SOM or SOC accumulation) in created wetlands. However, SC groups highlighted that soil development can also be affected by other variables leading to heterogeneity within a wetland (Table 3). BR consisted of five plots, four of which were classified in SC1 and one in SC3, showing variability in SC at the same wetland created at the same time. A trajectory of soil development was apparent with the higher SC group (i.e., more mature soil properties), showing higher TOC and DEA rates that are indicative of mature structural and functional development of created wetlands. Thus measuring soil physicochemical variables and determining SC differences can better identify ways to improve site-level functional development examination. The association between SC and functional development (e.g. denitrification) was indirectly explored by Sutton-Grier et al. (2011), where the focus was on vegetation influence on DEA rates. In that study, variations in soil resources were found to be important in determining the level at which the plant community contributed to functional development (Sutton-Grier et al. 2011). The denitrification function of wetlands is an essential ecosystem service that natural wetlands provide, and as such, should be required to be attained within the monitoring period of mitigation wetlands. Since the outcome of the study showed a clear linkage between DP development and soil maturation it is recommended that soil properties be included in post-construction monitoring of created mitigation wetlands.

Conclusion

The study demonstrates that denitrification function that is important for the ecosystem service of water quality improvement by wetlands is associated with the conditions and/or developmental stages of wetland soils. Site age does not necessarily equate with soil maturation with functional developmental rates varying both within and among sites. SC groups turned out to be useful in examining the functional development of created mitigation wetlands. Maturity in SC with accumulation of TOC and TN, the increase of GSM, and the decrease of D_b. seemed positively associated with DP development. The ranges of soil pH found in this study were fairly limited within the characteristic ranges of acidic soils in the Virginia Piedmont, but a further study is necessary to investigate the impacts of soil pH in acidic wetland soils on DEA rates and the relations among the SC attributes explored in this study. Nonetheless, the inclusion of soil properties in post-construction monitoring of created mitigation wetlands seems necessary to enhance our understanding and prediction of the development trajectory of an important biogeochemical function (i.e., denitrification).

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TABLE 1. Site level soil physicochemical attributes and denitrification rate (mean ± standard error)

	Created wetlands				Natural wetlands			
Site:	LC1	LC2	BR	NF	BP	BN	*F*	*p*
Age (years):	4	4	8	11				
SOM (%)	4.9 ± .29[a]	2.8 ± .16[b]	3.2 ± .28[b]	4.4 ± .16[a]	3.0 ± .19[b]	5.3 ± .70[a]	*14.8*	**
pH	5.3 ± .09[b]	5.1 ± .09[b]	5.3 ± .11[b]	6.5 ± .07[a]	4.3 ± .09[c]	5.6 ± .06[b]	*91.5*	**
TOC (%)	1.9 ± .11[a]	0.9 ± .10[b]	1.1 ± .14[b]	1.2 ± .06[b]	1.1 ± .07[b]	2.1 ± .38[a]	*10.6*	**
TN (%)	.18 ± .009[a]	.09 ± .009[b]	.11 ± .013[b]	.11 ± .004[b]	.08 ± .007[b]	.20 ± .029[a]	*15.2*	**
GSM (%)	34 ± 2.9 [bc]	33 ± 1.4[c]	31 ± 2.1[c]	39 ± 1.5[ab]	31 ± 1.5[c]	43 ± 3.4[a]	*5.95*	**
DEA rate (µg N-N2O/kg soil/h)	228 ± 39[a]	143 ± 42[ab]	123 ± 34[b]	41 ± 11[c]	124 ± 51[b]	115 ± 48[bc]	*3.22*	**

*Different letters between SC groups indicated significance at a $\alpha < 0.05$ after Bonferroni pairwise t-tests.
**$p < 0.05$

TABLE 2. Soil physicochemical attributes and denitrification rate (mean ± standard error) differences by sampling periods

	December	April	June	*F*	*p*
SOM (%)	4.5 ± .22[a]	3.6 ± .26[b]	3.4 ± .13[b]	*7.17*	**
pH	5.3 ± .10[b]	5.8 ± .12[a]	5.7 ± .13[ab]	*4.12*	**
TOC (%)	1.6 ± .11[a]	1.2 ± .11[b]	1.1 ± .07[b]	*5.84*	**
TN (%)	0.14 ± .01[a]	0.1 ± .01[b]	0.1 ± .01[b]	*6.42*	**
GSM (%)	40 ± 1.6[a]	35 ± 1.3[b]	30 ± 1.0[c]	*12.8*	**
Temperature (ºC)	1.3 ± 0.2[c]	12.8 ± 0.4[b]	20.5 ± 0.3[a]	*631*	**
DEA rate (µg N-N2O/kg soil/h)	75 ± 18 [a]	139 ± 16 [a]	119 ± 26 [a]	2.87	*0.06*

*Different letters between SC groups indicated significance at a α < 0.05 after Bonferroni pairwise t-tests.
**$p < 0.05$

TABLE 3. Summary of the soil physicochemical attributes and denitrification rate (mean ± SE) by wetland soil condition (SC)

	SC1 n = 10	SC2 n = 5	SC3 n = 5	*F*	*p*
LC1			2		
LC2	3				
BR	4		1		
NF	1	5			
BP	2				
BN			2		
SOM (%)	3.1 ± 0.2[b]	4.3 ± 0.2[a]	4.9 ± 0.4[a]	*12.2*	**
pH	5.2 ± 0.2[b]	6.6 ± 0.1[a]	5.4 ± 0.1[b]	*14.6*	**
TOC (%)	1.0 ± 0.1[b]	1.2 ± 0.0[b]	1.9 ± 0.2[a]	*18.2*	**
TN (%)	0.1 ± .01[b]	0.1 ± .00[b]	0.2 ± .02[a]	*24.9*	**
GSM (%)	32 ± 1.0[b]	39 ± 2.4[a]	38 ± 2.1[a]	*6.82*	**
Db (g/cm^3)	1.4 ± .03[a]	1.2 ± .02[b]	1.2 ± .06[b]	*9.6*	**
DEA rate (µg N-N2O/kg soil/h)	119 ± 16[b]	32 ± 6[c]	177 ± 25[a]	*17.4*	**

*Different letters between SC groups indicated significance at a α < 0.05 after Bonferroni pairwise t-tests.
**$p < 0.05$

TABLE 4. Spearman rank correlation among measured soil attributes and denitrification potential rates (i.e., DEA rates).

	SOM	pH	TOC	TN	GSM	DNT rate
SOM (%)	-					
pH	0.352	-				
TOC (%)	**0.767**	0.022	-			
TN (%)	**0.728**	-0.006	**0.902**	-		
GSM (%)	**0.574**	0.268	0.415	0.446	-	
DEA rate (ug N-N2O/kg soil/h)	-0.053	-0.258	0.147	0.156	0.179	-

Values in boldface indicate that correlation is significant at $\alpha < 0.01$ level and values underlined indicate that the correlation is significant at $\alpha < 0.05$.

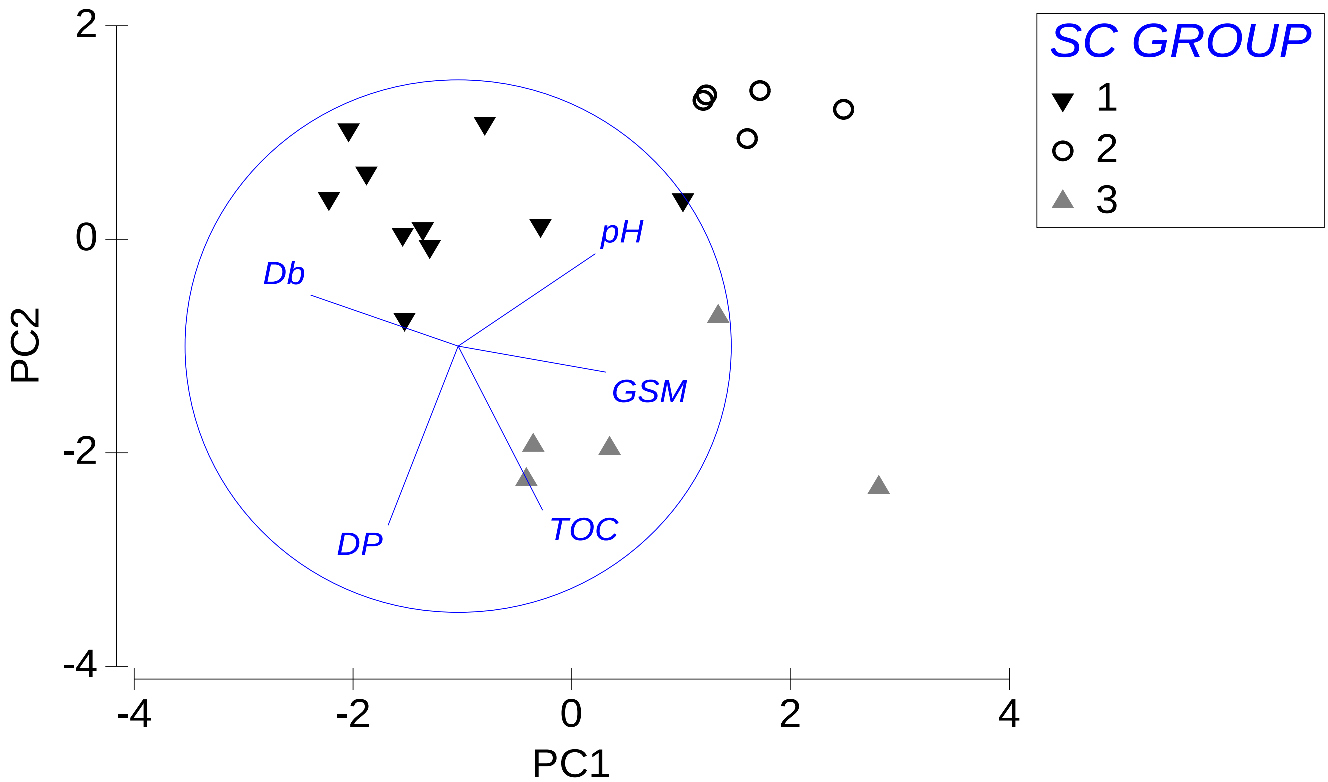

FIG. 1. Principal component analysis of soil properties(Db, pH, GSM, and TOC) and average denitrification potential (DP) of soils collected in the study during all four sampling periods. Symbols represent the plots at the indicated wetland soil condition (SC). SC1<SC2<SC3 less to more developed

Bacterial community structure of *nir*K-bearing denitrifiers is associated with the development of soil properties in created mitigation wetlands

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Abstract

We investigated the abundance and genetic heterogeneity of bacterial nitrite reductase genes (*nir*) in relation to soil structural attributes in created and natural non-tidal freshwater wetlands in Virginia. Soil attributes included soil organic matter (SOM), total organic carbon (TOC), total nitrogen (TN), pH, gravimetric soil moisture (GSM), and bulk density (D_b). A subset of soil attributes were analyzed across the sites, using euclidean cluster analysis, resulting in three soil condition (SC) groups of increasing wetland soil development (i.e., SC1<SC2<SC3 less to more developed) as measured by accumulation of SOM, TOC, TN, the increase of GSM, and the decrease of D_b. *Nir*K gene copies detected ranged between 3.6×10^4 and 3.4×10^7 copies g^{-1} soil and were significantly higher in the most developed soil group, SC3, than in the least developed soil group, SC1. However, the gene copies were lowest in SC2 that had a significantly higher soil pH than the other two SC groups, indicating a possible association between bacterial community structure and soil pH. Gene fragments were amplified and products were screened by terminal restriction fragment length polymorphism (T-RFLP)

analysis. Among 146 different T-RFs identified, fourteen were dominant and together made up more than 65% of all detected fragments. While SC groups did not relate to whole *nirK* communities, most soil properties that identified SC groups did significantly correlate to dominant members of the community. The outcome of the study suggests that the use of SC groups may be useful to examine the structure of bacterial communities that are critical for the functional development of created mitigation wetlands.

Keywords: denitrifying bacterial community, wetland soil, T-RFLP, qPCR, soil physicochemistry, created mitigation wetlands

1. Introduction

Mitigation wetlands are created and/or restored as a result of the national policy of 'no net loss,' which mandates the amelioration of the loss of wetland services through creation, replacement or enhancement (National Research Council, 2001). Previously, many mitigation projects have been generally unsuccessful in meeting the performance criteria that have been legally mandated (Zedler, 1996; National Research Council 2001; Ballantine and Schneider, 2009). Even successful cases of mitigation wetlands often fail or turn out to be slow in developing soil properties that are critical for the development of more complex functional attributes of wetlands (Wolf et al., 2011). Created and restored wetlands tend to show lower levels of organic C and N, higher bulk densities, and lower productivity than their natural counterparts (Craft et al., 2002; Bruland and Richardson, 2005; Fennessy et al., 2008). Wetland soils serve as sites of important biogeochemical processes that contribute to the myriad of ecosystem services for which wetlands are recognized (e.g. nutrient cycling and water quality improvements). The degree to which soil physicochemical properties mature to resemble natural soils in created wetlands is critical for both vegetation community development (Dee and Ahn, 2012) and the development of a biogeochemical function (e.g., denitrification) (Wolf et al., 2011).

Still, in most cases of wetland mitigation, vegetation has been used as the sole measure of mitigation success (Breaux and Serefiddin, 1999; Spieles, 2005). Relying on vegetation alone leaves out soil physicochemical (e.g. soil moisture, pH, C content) and biological (e.g. bacterial communities) attributes that are mostly responsible for the functional development of wetlands. With increasing age and additional plant growing seasons, the soil properties of a created wetland should mature and develop. An excellent indicator of soil development and quality is

SOM content (Howard and Howard, 1993; Bruland and Richardson, 2005), as it is a major source of nutrients (especially N) (Sollins et al., 1999). SOM provides both organic N, the substrate of mineralization, and organic carbon, which is a required energy source of both mineralizing and heterotrophic denitrifying microbes (Beauchamp et al., 1989; Groffman, 1994; Hill and Cardaci, 2004). SOM provides the energy source and nutrients necessary for bacterial growth that can directly limit or enhance the development of ecological functions (Strauss and Lamberti, 2000; Wolf et al., 2011). The ability of wetlands to support diverse metabolic and catabolic processes depends on the ability to support anaerobic and aerobic environments (Ogram et al., 2006), which are directly affected by SOM and the resulting water holding capacity (D'Angelo et al., 2005; Wolf et al., 2011).

Denitrification is one of the key ecological functions of natural wetlands extensively studied (Groffman, 1994; Hunter and Faulkner, 2001; Hill and Cardaci, 2004). It is a dissimilatory metabolic process that integrates a series of reductions to convert nitrate (NO_3^-) to dinitrogen (N_2), resulting in a loss of fixed nitrogen from the system. The initial reduction from NO_3^- to NO_2^- is facilitated by the synthesis of nitrate reductase under anaerobic conditions and with the presence of NO_3^-. Subsequently, NO_2^- can be reduced to NO, then N_2O and finally to N_2. The last three products being gases, released to the atmosphere at rates dependent on the efficiency of the denitrification processes, are important to water quality functions and climate change implication of wetlands. The sequential biogeochemical reactions can be carried out by one organism or may be carried out by different members of the microbial community. Denitrifying bacteria play a significant role in the denitrification function of wetlands (Groffman, 1994). It is known that denitrifiers constitute a taxonomically diverse functional guild with members belonging to all three domains, including more than 60 genera of bacteria, and they can represent up to 5 % of the total soil microbial community (Fierer and Jackson, 2006; Demaneche et al., 2009). The assumption that the composition of the denitrifying community is of minor importance in controlling denitirification has been challenged by studies including those of Cavigelli and Robertson (2000), and Holtan-Hartwig et al. (2000), which suggested that denitrifier communities vary in their tolerances to environmental stresses. Therefore, denitrifying bacterial communities may act as a medium through which environmental controls on denitrification are realized. Wallenstein and others (2006), in a literature review of environmental controls over denitrification, noted that C availability, pH, moisture and temperature are key factors in determining denitrifying community structure. Specifically, it has been suggested that increased soil organic carbon can be associated with bacterial diversity and may control the enzymatic/metabolic rates of the bacterial communities responsible for N processing (D'Angelo et al., 2005; Ahn and Peralta, 2009; Chen et al., 2010; Dandi et al., 2011).

We studied soil physicochemical properties and denitrifying bacteria community structure in created and natural wetlands in the Piedmont region of Virginia. Specifically we hypothesized that soil conditions (i.e., development and/or maturation) in created wetlands would be associated with the abundance and genetic heterogeneity of denitrifying bacterial communities.

2. Materials and methods

2.1. Site descriptions

Five non-tidal freshwater wetlands located in the Piedmont physiographic region of northern Virginia were chosen for this study (mean annual precipitation 109 cm, mean temperature min 7 ºC/ max 18ºC). Three of the wetlands are mitigation wetlands created by

Wetland Studies and Solutions Inc. (WSSI) on old farmland with a predominantly herbaceous cover. The other two are natural wetlands and include bottomland riparian forested wetlands and open herbaceous wetlands.

All created wetlands contain at least a 0.3 m low permeability subsoil layer covered with the original topsoil from the site that was supplemented with commercially available topsoil to a depth of 0.2 m. This design creates a perched, precipitation-driven water table close to the soil surface and limits groundwater exchange in the wetland. Loudoun County Mitigation Bank (LC) is a 12.9 ha wetland and upland buffer complex, constructed in the summer of 2006 in Loudoun County, Virginia (39º1′ N, 77º36′ W). LC receives surface water runoff from an upland housing development and forested buffer, as well as minor groundwater inputs from toe-slope intercept seepage. LC consists of two wetland basins (LCs 1 and 2). LCs 1 and 2 are two contiguous sites separated by a berm and connected by a drainage channel with LC1 approximately 0.4 m higher in elevation than LC2. This design causes LC1 to drain more quickly leaving it inundated for shorter periods after precipitation than LC2, while LC2 can remain under standing water (e.g., < ~12 cm) for longer periods. Bull Run Mitigation Bank (BR) is a 20.2 ha wetland and upland buffer complex, constructed in 2002 in Prince William County, Virginia (38º51′ N, 77º32′ W). The site may receive water from Bull Run from a culvert structure that routes water via a central ditch through the wetland, as well as overbank flow from Bull Run, which sharply bends around the corner of the site. The wetland receives limited surface water runoff from wetlands and negligible groundwater. North Fork Wetlands Bank (NF) is a 50.6 ha wetland, constructed in 1999 in Prince William County, Virginia (38°49 ′ N, 77°40 ′ W). With the exception of minor contributions from toe-slope intercept seepage, the site is disconnected from the groundwater by an underlying clay liner. Study plots were located in two created hydrologic regimes: main pod area-fed by upland surface water runoff and a tributary of the North Fork of Broad Run that is controlled by an artificial dam; and vernal pool area - located in the south west quadrant of the wetland and fed solely by precipitation. All Vegetation in LC1, LC2 and BR is mostly herbaceous, interspersed with young tree saplings and shrubs in projected forested areas. NF vegetation includes diverse wetland herbs, shrubs, trees and submerged and floating vegetation supported by the varied hydrology. The tree communities are established and in some instances include communities extant at time of wetland creation.

Manassas National Battlefield Park (BP), is a 2,000 ha site with areas of natural wetland coverage located in Prince William County, Virginia (38º49′ N, 77º30′ W). Study plots were located in an area of herbaceous wetland within a matrix of forested floodplain. The site is connected to Bull Run by a culvert on its eastern end and also receives groundwater and upland surface water runoff. Vegetation is mostly herbaceous with a few mature trees interspersed throughout. Banshee Reeks Nature Preserve (BN) is a 290 ha site with areas of seep and riparian wetlands located in Loudoun County, Virginia (39º1′ N, 77º35′ W). These floodplain riparian wetlands receive water from groundwater springs, surface water runoff, and occasional overbank flooding from Goose Creek. Vegetation is a mixture of herbaceous plants dominated with mature wet bottomland forest.

2.2. Soil sampling

Soil samples were collected on four dates: October and December 2010 and April and June 2011. A total of 16 study plots in the created wetlands (e.g., LC, BR and NF) and 4 plots in the natural wetlands (e.g., BN and BP) were selected. Each plot was 100 m^2 (e.g. 10 m x 10 m) and was divided into four (e.g. 5 x 5 m) quadrants. Within each quadrant, three soil samples were taken at the depth of 5-10 cm from the top by use of an auger (1 1/4" diameter) at random and combined in a polyethylene bag. All samples were kept in a cooler with ice packs to slow bacterial activity until further processing in the laboratory. At the laboratory, each bag was homogenized manually to mix all three samples for each quadrant. Any visible root or plant material was manually removed prior to homogenization.

2.3. Soil physicochemical analyses

Sub-samples taken for SOM, total organic carbon (TOC), total nitrogen (TN) and pH were air dried. Once air dried, soils were macerated using a mortar and pestle and any large constituents (e.g. rocks and large organic debris) were removed. A Perkin-Elmer 2400 Series II CHNS/O Analyzer (Perkin-Elmer Corporation, Norwalk, CT, USA) was used to analyze percent TOC (~TC) and percent TN. Sub-samples (2-3 grams of air dried soil) were separated for SOM, loss on ignition (LOI) method (Wilson and Sanders, 1996), and oven dried at 105 ◦C for 24 hours, weighed and placed in 405 ◦C for 16 hours. SOM was calculated as the difference between the dry soil mass and the mass of the soil after oxidation of organic matter [(dry mass – ovened at 405 ◦C mass)/ (dry mass) x 100]. For gravimetric soil moisture (GSM), field-wet mass was measured and samples dried at 105 ◦C for 48 hours. GSM was calculated by: [(wet mass – dry mass)/(dry mass) x 100] (Gardner, 1986). For pH determination, 10 g air dried soil samples were combined with 10 mL of deionized water, swirled and left to stabilize for 10 minutes prior to measurement with pH meter (Thomas, 1986). Bulk density (D_b) (Blake and Hartge, 1986) was measured once during the study period in November 2010. D_b was determined by collecting 5 cm by 10.2 cm cores, weighing the entire field-moist core, converting to dry weight based on GSM percentage, and dividing by the total volume of the soil in the core (200.2 cm^3). Soil temperatures were measured using ibuttons (Embedded Data Systems Inc.) for each sampling periods, including a week before and after the period. The ibuttons are computer chips that contain temperature sensors and are encased in portable button sized capsules. All ibuttons were buried at each plot at a soil depth of 5 to 10 cm.

2.4. Microbial Community Analyses

2.4.1. Extraction of DNA

DNA was extracted from approximately 0.5-1 g of soil per sample using the UltraClean® Soil DNA Isolation Kit (MoBio Laboratories, Solana Beach, CA, USA) and following manufacturer's instructions. Extractions were quantified using the NanoDrop 1000 Spectrophotometer (Thermo Fisher Scientific, Willmington, DE, USA).

2.4.2. PCR amplification of nir fragments

Bacterial *nirK* gene fragments were amplified using the primer pair F1aCu - R3Cu (approximately 470 bp) developed by Hallin and Lindgren (1999). The forward primers (F1aCu) were 5'-end FAM labeled (Operon Inc.). PCR amplification was done with 50-µL reaction mixtures in 0.5 mL Eppendorf tubes. Each reaction contained 1µL of extracted DNA, 1.25 U of GoTaq® polymerase (Promega, Madison, WI, USA), manufacturer's reaction buffer containing 25 mM $MgCl_2$, 2.5 mM of each deoxynucleotide triphosphate, 1.2 µg/µL non-acetylated BSA, and 20 uM of each primer. The PCR was run in a Mastercycler® gradient cycler (Eppendorf, Hamburg, Germany) with an initial denaturing step of 4 min at 94°C; 35 cycles of denaturation at 94°C for 30 s, primer annealing at 59°C for 1 min, and extension at 72°C for 1 min; then a final extension at 72°C for 7 min. Products were confirmed by electrophoreses of 5 µL of each reaction on 1% agarose gel. Negative and positive controls were included in each experimental run.

Amplification of *nirS* gene fragments was attempted by PCR using primer pairs F1acd-R4cd (Hallin and Lindgren, 1999), and also primer pairs *nir*S1F-*nir*S6R developed by Braker et al. (1998). These amplifications yielded strong products for the positive control (*Pseudomonas stutzeri*), but faint if any amplification products in environmental samples. Since *nirS* gene detections were rare and faint, we focused on *nirK* gene amplification products for the study.

2.4.3. Terminal Restriction Fragment Length Polymorphism Analysis

Screening of the nitrite reducing bacterial communities was done by terminal restriction fragment length polymorphism (TRFLP) analysis. Amplified *nirK* fragments were digested with *HaeIII* (New England BioLabs, Beverly, Mass., USA) restriction endonuclease enzyme for at least 4 hours at 37°C. Aliquots (2-4 μL) of each digest were mixed with 12 uL deionized formamide and 0.5 μL of GeneScan-ROX500 (Applied Biosystems Instruments, Foster City, CA, USA) size standard. Mixtures were denatured for 3-5 min at 93°C in and snap cooled on ice for 2 minutes. Fragment lengths were determined by using an automated DNA sequencer, model ABI 310 (Applied Biosystems Instruments, Foster City, CA, USA). The fluorescently labeled fragments were detected and analyzed by the GeneMapper® v4.1 (Applied Biosystems Instruments, Foster City, CA, USA) software. Terminal restriction fragment (T-RF) peaks from all samples were aligned using the interactive binner script (Ramette, 2009) for R statistical software environment. T-RFs were only considered if sized between 50-400 bp with relative abundances greater than 1%. Most samples yielded detectable amounts of *nirK* gene fragments, except for samples collected in June 2010 for LC1 and BP.

2.4.4. Quantification of nirK gene copies

Quantitative PCR (qPCR) assays were used to quantify the abundance of *nirK* gene copies within soil bacterial communities, using the primer pair F1aCu - R3Cu (Hallin and Lindgren, 1999). QuantiTect® SYBR® green PCR kit (Qiagen Inc., La Jolla, CA) was used in 25 µL reactions containing 0.6µM of each primer, 1X quantitect SYBR green PCR master mix, and 1 µL of DNA template in a Stratagene MX3000P thermal cycler (Agilent Technologies, La Jolla, CA, USA). Run conditions included an initial denaturing step of 15 min at 95°C; 45 cycles of denaturation at 95°C for 30 s, primer annealing at 55°C for 30 s, and extension at 72°C for 1 min; then a final cycle of 95°C for 30 s, 55°C for 30 s and 95°C for 30 s. No template controls were included in each experimental run, and melting curves were also performed to assess product integrity. Standard curves were obtained with serial plasmid dilutions of a known amount of plasmid DNA containing a fragment of the *nirK* gene, and runs with amplification efficiency > 90% were deemed acceptable. Assay sensitivity was 10 copies. Inhibitory effects of coextracted substances were tested by spiking one of three replicates with the 100 copy *nir*K bearing plasmid to confirm amplification of correct abundances.

2.5. Data analyses

Soil condition (SC) groups were determined by cluster analysis at 70% similarity of soil physicochemical parameters that included pH, GSM, Db, TOC and TN. Statistical significance of the SC groups was verified by applying a similarity profile test (SIMPROF) which performs permutation tests at each node of the cluster analysis dendogram. SIMPROF thus determines whether each cluster set has significant ($\alpha = 0.05$) evidence of a multivariate pattern different from the rest (Clarke and Gorley, 2006). We compared physicochemical and nitrite reducer community assemblages using multivariate analysis of similarities (ANOSIM) (Clarke and Gorley, 2006; Ahn and Peralta, 2009). Additionally, principal component analysis (PCA) was used to visualize 'best fit' of plots along soil physicochemical properties. All test described thus far were performed using PRIMER 6, version 6.1.5 (Primer-E Ltd., Plymouth, United Kingdom). PCA-generated principal coordinates were used for further analysis in bivariate regressions. Shannon–Weiner's diversity index (H') (Hill et al., 2003) was calculated based on the observed fragment peak areas generated by T-RFLPs of the wetland soils.

Analysis of variance (ANOVA) was used to compare soil physicochemical variables, T-RF diversity and *nirK* gene copies abundance, all between SC groups. Dunnett's posthoc tests for uneven variances were carried out for each ANOVA to determine between-group differences. ANOVAs and regressions were conducted using SYSTAT 12 (Cranes Software International Ltd).

Redundancy analysis was performed on denitrifying bacteria community composition based on *nirK* gene T-RFLP. Soil physicochemical attributes used for redundancy analysis (RDA) included pH, SOM, TOC, TN, GSM and temperature (°C). RDAs were carried out using CANOCO, version 4.5. (Biometrics-Plant Research International, Wageningen, Netherlands). The significance of the relationships between the soil physicochemical attributes and the T-RFs were calculated by use of Monte Carlo permutations and $p<0.05$ were considered non random.

3. Results and Discussion

3.1. Soil properties by wetland site

We did not observe an age-related maturation of soils in the wetlands (Table 1). SOM and TN were significantly higher in the forested natural wetland (BN), the oldest created wetland (NF) and one of the youngest created wetlands (LC1) with SOM contents of 4.1% up to 5.6% and TN from 0.24% to 0.48% (Table 1). TOC content was highest in LC1 and BN with values averaging 1.9% and 2.0%, respectively. LC1 showed a significantly higher TOC content than the same-aged LC2, indicating that Soil properties varied both within and among sites (Table 1). Soil pH was significantly higher in NF (6.4) and lower (4.3) in BP (Table 1). Soil pH in the other wetlands (e.g. LC1, LC2, BR and BN) ranged from 5.0 to 5.6 with no significant differences between these sites (Table 1), showing a typical, acidic characteristic of the soils of Virginia Piedmont (Farrel and Ware, 1991). GSM was highest in BN soils where the average was 43%, but there was no significant difference of GSM between the rest of the sites (Table 1). Spatial variability of soil attributes in both created and restored wetlands were found and discussed in previous studies (Bruland and Richardson, 2005; Bruland and Richardson, 2006). The outcome of the study showed no relationship between site age and soil maturation measured in SOM, TOC and GSM,

3.2. Soil properties by SC groups across the sites

Soil properties develop through the accumulation of SOM which is closely associated to age related factors such as seasonal plant senescence (Ballantine and Schneider, 2009). However, age based soil development trajectories have been found to be highly variable and not predictive of plant community development (Wolf et al., 2011; Dee and Ahn, 2012). SOM accumulation can vary due to variables that may facilitate or impede autochthonous (e.g. seasonal plant senescence) and allochthonous or allogenic (e.g. sediment brought by flooding or runoff) sources of organic matter. The construction process itself can compact soils increasing Db and decreasing microtopography leading to a loss in water holding capacity and loss of SOM (Moser et al., 2009). Therefore comparison of soil development within and between wetland sites may be better achieved by identifying soil attributes that contribute to soil development. Accumulation of SOM, TOC, and TN along with the resulting lower Db and increased GSM have been identified as structural attributes of soil development (Craft et al., 2002; Bruland and Richardson, 2005; Hossler and Bouchard, 2010; Wolf et al., 2011) and significantly correlated with plant community establishment (Dee and Ahn, 2012) and nitrogen cycling (Wolf et al., 2011).

We compared plots across four created and two natural wetlands by grouping them along a SC gradient. SC groups were identified by cluster analysis of all plots discriminated by five easily measured soil physicochemical properties; pH, GSM, Db, TOC and TN. SC groups effectively discriminated plots according to progressive soil development/maturation (e.g., SC1<SC2<SC3), irrespective of site (Table 2). SOM ranged on average from 3.2% in SC1 to 5.0% in SC3 and was significantly different for each group ($p<0.01$). While TOC and TN are closely related to SOM, there was no difference in TOC and TN contents between SC1 and SC2 ($p>0.05$). TOC and TN were highest in SC3 ($p<0.05$) which on average had contents of 2.0% and 0.2% respectively (Table 2). Db and GSM followed a similar pattern indicating that SC1 was the least mature group having higher Db ($p<0.01$) and lower GSM ($p<0.01$; Table 2). These values indicate mineral soils and are comparable to young (e.g., <20 years old) created wetlands in Virginia (TOC 0.3-4.0%) (Moser et al., 2009), North Carolina (SOM 0.6-4.03, Db

0.99-1.64 $g^{-1}cm^3$) (8), and New York (SOM 6.2%, Db 1.1 $g^{-1}cm^3$) (Ballantine and Schneider, 2009). Natural wetlands were also included in the SC groups and while SOM and TOC contents are lower than reported in Pennsylvania (SOM mean 11.5%) (Campbell et al., 2002) and Maryland (TOC mean 5.7%) (Hogan et al., 2004) they were comparable to other Virginia natural sites (0.7-7.7%) (Moser et al., 2009).

3.3. Abundance of nitrite reducers by qPCR

Denitrifying bacterial community abundances were assessed by quantifying the number of *nirK* functional gene copies per sample. *Nir*K gene copies ranged between 3.8×10^4 and 3.4×10^7 copies g^{-1} dry soil weight among all soil samples. To account for any differences in biomass between samples, we also calculated the abundance of copies normalized to the amount of extracted DNA, which ranged from 1.2×10^2 to 4.4×10^3 copies ng^{-1} extracted DNA. The gene copy numbers by SC groups ranged between 2.2×10^4 and 1.1×10^7 copies g^{-1} dry soil weight, and from 1.1×10^2 to 2.3×10^3 copies ng^{-1} extracted DNA (Table 2).

While it is difficult to find comparable studies in constructed wetland soils quantifying *nirK* genes, our gene copy abundances were lower than those published in one study of denitrifying community abundances in free water surface constructed wetlands, which had a range between 1.6×10^9 and 2.1×10^{11} *nir*K copies g^{-1} soil (Garcia-Lledo et al 2011). However, these wetlands were significantly different from those in this study in that they were from a treatment wetland for water quality improvement, and the study consisted of sites with continuously waterlogged sediments planted with *Phragmites* and *Typha*. Our study consisted of wetland sites constructed from former farmland with primarily herbaceous cover, with no wastewater treatment component. Other more comparable values were found in studies looking at *nir*K gene copy abundances in various soils (9.7×10^4 to 3.9×10^6 copies g^{-1}) (Henry et al., 2004) and organic humus in south Bohemia (2.7×10^4 to 1.2×10^6 copies g^{-1}) (Barta et al., 2010).

Abundances of *nir*K gene copies, whether calculated per gram soil or per ng of DNA, were greater in the plots with greater SOM, TOC, TC, GSM and lower D_b when comparing soils of similar pH (Table 2). SC3 plots had the highest abundance ($p=0.02$) followed by SC1 (Table 2). Denitrification is a facultative process that requires anaerobic conditions, such as those observed in inundated soils. The more developed SC plots have higher levels of SOM which not only provide an energy source but also can contribute to lower Db. The lower Db in turn increases pore space that allows for greater water retention and may lead to higher GSM. The resulting soil matrix is better able to maintain anoxic conditions, that may be able to give an advantage to those bacteria that are able to use an alternate (i.e. NO^-_2) terminal electron acceptor than O_2.

When pH was considered, the lowest *nir*K gene abundances occurred in soils with higher pH (i.e. SC2). SC2 had the pH of 6.6, being significantly higher than those in the other SC groups, and contained an order of magnitude less gene copies than either SC1 or SC3 (Table 2). The relationship between higher pH and low copy numbers was not limited to SC2 plots. A bivariate regression of soil pH and *nir*K abundances in our study revealed that the gene copy numbers in our soils have a negative correlation with increased pH ($R=0.27, p=0.03$). pH has been extensively researched as an environmental factor affecting bacterial communities (Fierer and Jackson, 2006; Lauber et al., 2009). Among the few studies that have specifically linked *nir*K communities to pH, Barta and others (2010) found that *nir*K gene abundances had a positive relationship with pH. Furthermore, they found that in Bohemian Forest soils the lower threshold was a pH of 5. The results showed that this relationship may not apply consistently to all soil types (Parkin et al., 1985; Wallenstein et al., 2006) and may suggest that the denitrifying community was adapted to low pH (e.g., $< pH\ 6$) in our soils studied. However, the characterization of the community has not been made. Philippot and Hallin (2005) characterized microbial communities, but their correlation with denitrification parameters was unclear. In fact, the effect of pH is not necessarily a direct one on the denitrification processes, and may be more related to other environmental and biological factors (Simek and Cooper, 2002). For instance, the availability of organic carbon and other nutrients can be diminished in acidic environments, leading to lower energy source and reducing the activity of the heterotrophic microbial community as a whole and the denitrifying community in particular (Simek and Cooper, 2002). No information is currently available on what the conditions favorable for denitrification at low pH are and how they would be related to the quantity and diversity of certain species or communities. Further study is needed.

To further link the relationship between nitrite reducers and soil condition groups we looked at the PCA of physicochemical attributes (Fig. 1) which clearly demonstrated SC groupings. Sixty two percent of all the variation between plots was explained by PC1, which was negatively related with TOC, TN and GSM (Fig. 1). PC1 was also negatively correlated with *nir*K abundances (*adjusted* $R=0.23, p<0.01$), indicating that as TOC, TN and GSM (i.e., % moisture) values increased so did the nitrite reducing community. PC2 was positively correlated with pH and was not significantly correlated to *nir*K gene abundances ($p=0.63$).

Since gene copy numbers do not measure activity and denitrification is a facultative process, the abundance of nitrite reducers is not in and of itself indicative of functional development. However, the abundance of a functional gene (e.g. *nir*) in a community may be used as a baseline for comparing potentials for functional development. Relating the abundances with SC attributes further can indicate a link between the soil structural controls and their effects on functional development. Nitrogen flux rates, for example, can increase with soil structural measures equivalent to SC (see Wolf et al., 2011). The increased nutrient availability and energy source in soils with higher SOM content, along with moisture retention that enable lower redox potentials, do affect potential denitrification rates (Wolf et al., 2011). Our results show that nitrite reducers are responsive to soil development, (e.g. increased SOM, TOC, TN and GSM and lower Db) and their abundance may serve as good surrogates for functional development in terms of N cycling in created wetlands.

3.4. Denitrifying community patterns (T-RFLP).

The denitrifying bacterial communities from plots classified by one of the three SC groups were evaluated by T-RFLP analysis of the amplified *nir*K gene fragments. While it is important to keep in mind potential biases from differential PCR amplification in using peak areas for TRLP community structure analysis, it has been found to be a useful tool in delineating structure between samples. We detected a total of 146 different T-RFs in all of the samples. The average numbers of fragments observed in each group were 131, 99 and 110 for SC1, SC2 and SC3, respectively. *Nir*K gene based community structures were not explained by SC groupings (ANOSIM *Global* $R=0.046$, $p=0.1$). Diversity values ranged from 2.7 to 3.2, and no significant difference was found by SC type (Table 1). These values are lower than a comparable study using T-RFLPs to assess *nirK* gene diversity in marsh (H' = 3.6) and upland (H' = 4.4) soils in Michigan (Prieme et al., 2002). Admittedly the comparison is somewhat limited due to the range of primers and methods used to study denitrifying bacteria communities.

Considering the effect of rarer species on diversity values we identified fourteen T-RFs, from the 146 detected, which together made up more than 65% of all detected T-RFs. Dominant T-RFs did correspond to four main factors; 1) pH, 2) TN, 3) temperature and 4) GSM, SOM and TOC (Fig. 2). Specifically we found three fragments (e.g., T-RFs-311, 277 and 141) were positively correlated with TN and negatively with pH (Fig. 2). While two (e.g., T-RFs 281 and 313) increased in relative abundance with decreasing pH and lower TN (Fig. 2). Four fragments (e.g., T-RFs 131, 173, 243 and 337) increased along with soil maturity reflected in increased GSM, SOM and TOC (Fig. 2). Four others (e.g., T-RFs 135, 141, 209 and 275) were positively correlated with temperature (Fig. 2). The importance of dominant T-RFs in *nirK* soil communities was explored by Wertz et al. (2009) in Canadian agricultural soils, which compared whole and active (using mRNA transcripts from entire community) *nirK* community composition, concluding that the active portion was relatively stable and more abundant in all sampled soils. This kind of variation in *nirK* community structure has also been observed in stream sediments along an urbanization gradient (Wang et al., 2011). The study revealed *nir*K (and *nos*Z) community shifts in stream sediments along a gradient of soil conditions (measured by TN, TOC, and pH) that changed with urbanization. Another study by Peralta et al. (2010) revealed that soil moisture and soil fertility were associated with differences in denitrifying microbial community structure. All of these studies show that *nirK* bearing denitrifiers respond to physicochemical changes in the environment, making *nirK* community structure assessment a useful tool.

Relative abundance shifts of the dominant T-RFs were apparent by SC groups (Fig. 3). Two dominant fragments (e.g., T-RFs, 277 and 275) had higher relative abundances in SC1, while two others (e.g., T-RFs 209 and 173) had lowest abundances in this group. SC2 plots collectively had lower abundance of four dominant fragments (e.g., T-RFs 135, 275, 279 and 281) and highest of fragment 119. SC3 had the most evenly distributed abundance profile and had the highest abundance of T-RF-135 (Fig. 3). These results highlight the relationship between soil maturation and the structural characteristics of a biological component of the denitrification process. The *nir*K bearing denitrifier communities in the wetlands seem to be dominated by a few members that respond to soil properties of which development is critical for ecosystem functional development in created mitigation wetlands.

4. Conclusion

We investigated a subset of soil denitrifying communities and soil properties in created and natural wetland soils in the piedmont region of Virginia. SC groups effectively managed to organize study plots across sites according to soil development using five easily measured soil properties; TOC, TN, Db, pH and GSM. SC groups showed a significant association with *nir*K bearing denitrifiers in terms of abundance, with its greater abundance associated with the soil properties indicative of wetland maturation. The ranges of soil pH found in this study were fairly limited within the characteristic ranges of acidic soils in the Virginia Piedmont, but the results of the study reveals that a further study is necessary to investigate the impacts of soil pH in acidic wetland soils on the structure of *nir*K bearing denitrifier communities. While SC groups did not relate to whole *nir*K community structure, soil attributes that identified SC groups did significantly correlate with a number of dominant members of the community. The study happened to be limited to a single gene (i.e., *nir*K community) in the denitrification pathway and might represent an incomplete picture of the potential denitrification communities in the system. Nonetheless, soil properties and their maturation seemed closely associated with bacterial communities that are important in developing a biogeochemical function (i.e., denitrification) and can be used in post-construction monitoring of created mitigation wetlands to better assess their functional development in the future.

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TABLE 1. Soil properties by wetland site in the study (mean ± standard error)

	Created wetlands				Natural wetlands			
Site:	LC1	LC2	BR	NF	BP	BN	*F*	*p*
Age (years):	4	4	8	11				
SOM (%)	4.8 ± 0.2[a]	3.1 ± 0.2[b]	3.2 ± 0.2[b]	4.3 ± 0.2[a]	3.3 ± 0.3[b]	5.2 ± 0.4[a]	*19.4*	**
pH	5.3 ± 0.1[b]	5.1 ± 0.1[b]	5.3 ± 0.1[b]	6.4 ± 0.1[a]	4.3 ± 0.1[c]	5.5 ± 0.1[b]	*71.5*	**
TOC (%)	1.9 ± 0.1[a]	1.0 ± 0.1[b]	1.1 ± 0.1[b]	1.1 ± 0.0[b]	1.2 ± 0.1[b]	2.0 ± 0.2[a]	*19.4*	**
TN (%)	0.34 ± .10[a]	0.28 ± .08[b]	0.25 ± .06[b]	0.37 ± .10[a]	0.25 ± 0.10[b]	0.38 ± 0.10[a]	*15.3*	**
GSM (%)	34 ± 3[b]	33 ± 1[b]	32 ± 1[b]	36 ± 2[b]	31 ± 2[b]	43 ± 1[a]	*6.4*	**

*Different letters between sites indicated significance at $\alpha < 0.05$ after Dunnett's T3 post-hoc tests.
**$p < 0.05$

TABLE 2. Summary of the soil chemical and bacterial community attributes (mean ± SE) by wetland soil condition (SC) groups*

	SC1 n=10	SC2 n=5	SC3 n=5	*F*	*p*
LC1			2		
LC2	3				
BR	4		1		
NF	1	5			
BP	2				
BN			2		
SOM (%)	3.2 ± 0.1^{c}	4.4 ± 0.1^{b}	5.0 ± 0.2^{a}	49.9	**
pH	5.2 ± 0.6^{b}	$6.6 \pm .05^{a}$	$5.4 \pm .04^{b}$	137	**
TOC (%)	$1.1 \pm .03^{b}$	$1.2 \pm .03^{b}$	$2.0 \pm .13^{a}$	53.5	**
TN (%)	0.1 ± 0.0^{b}	0.1 ± 0.0^{b}	$0.2 \pm .01^{a}$	60.2	**
GSM (%)	32 ± 1^{b}	37 ± 1^{a}	39 ± 1^{a}	20.8	**
Db (g/cm3)	$1.4 \pm .03^{a}$	$1.2 \pm .02^{b}$	$1.2 \pm .06^{b}$	9.6	**
nirK copies per g of soil (x 10^4)	260 ± 170^{b}	29 ± 6.7^{c}	950 ± 120^{a}	3.8	**
nirK copies ng-1 DNA (x 10^2)	9.8 ± 4.3^{b}	$1.4 \pm .31^{c}$	20 ± 2.5^{a}	2.6	**
Diversity (H')	2.8 ± 0.1^{a}	2.9 ± 0.2^{a}	3.1 ± 0.1^{a}	0.7	0.4

*Different letters between SC groups indicated significance at a P of < 0.05 after Dunnett's T3 post-hoc test. Letters were omitted if there were no significant differences among SCs.
**p < 0.05

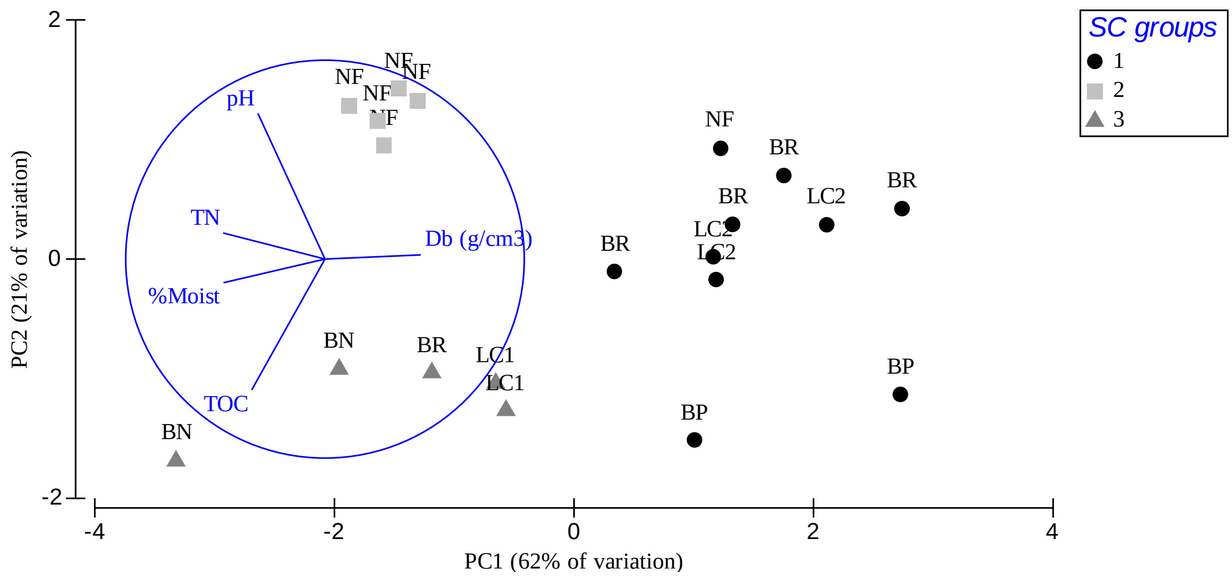

FIG. 1. Principal component analysis (PCA) of physicochemical attributes of soils collected in the study during all four sampling periods. Symbols represent the plots at the indicated wetland soil condition.

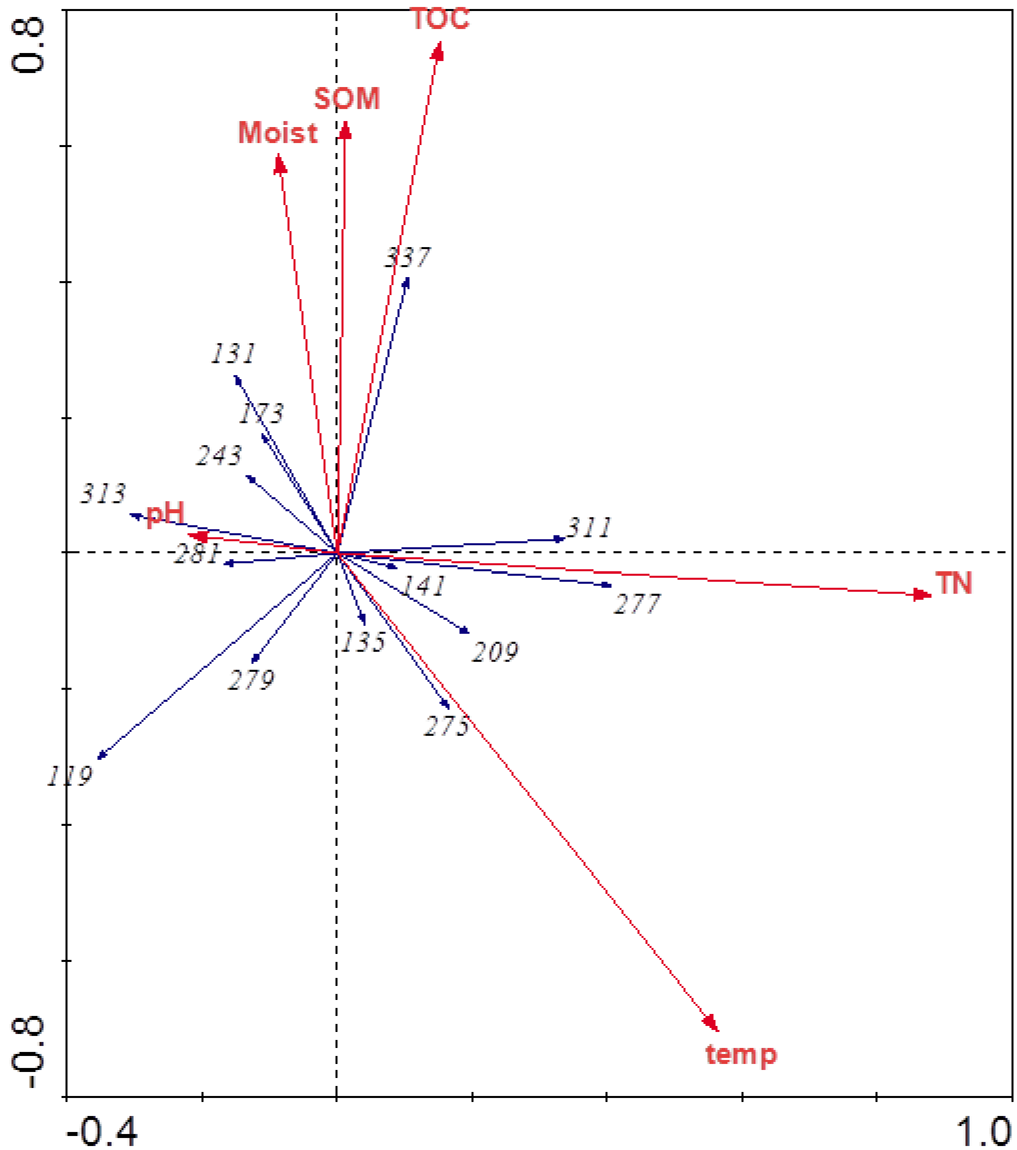

FIG. 2. Redundancy analysis diagram of *nirK* community major T-RFs and soil property variables defined by the first and second axes. Arrows represent the relationship between soil physicochemical attributes and the major denitrifiers in the communities.

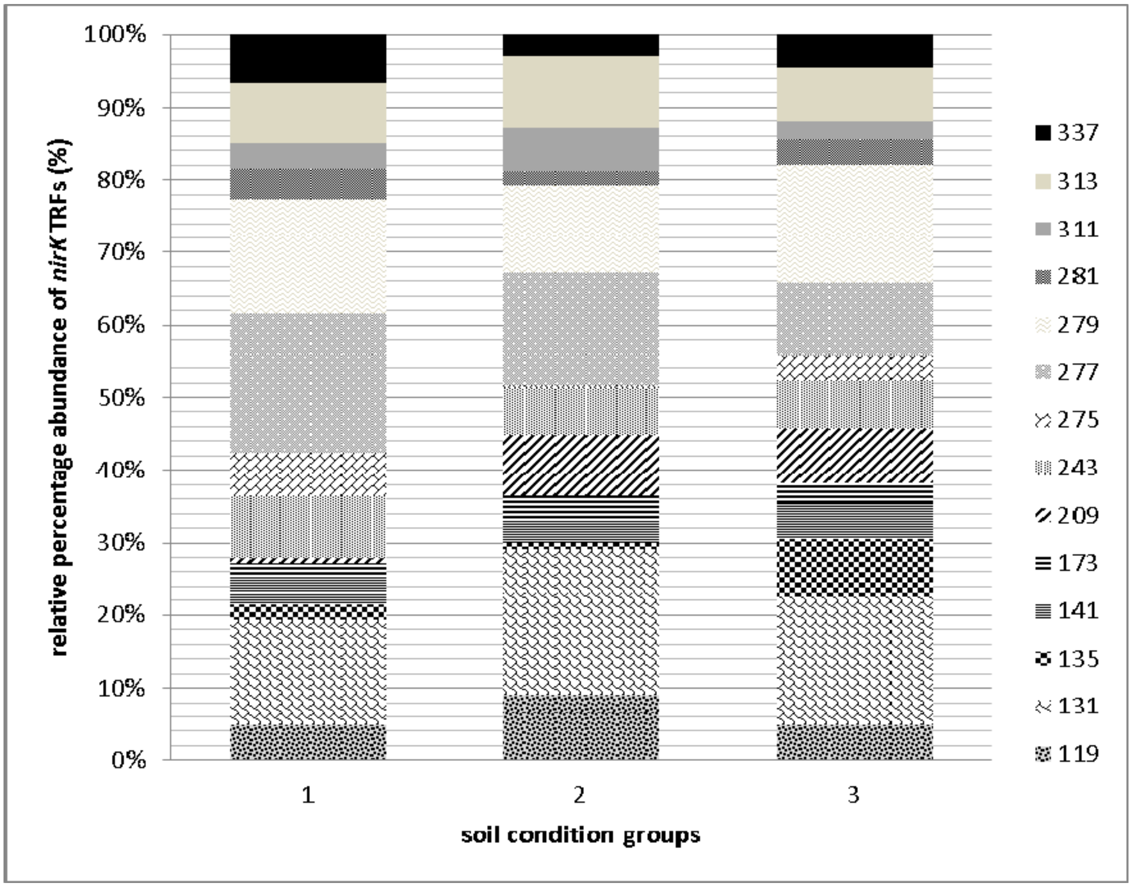

FIG. 3. Relative percentage abundance of major *nirK* community T-RFs by SC groups.

USGS Award # G11AP20207 Modernizing U.S. Army Corps of Engineers Planning and Regulatory Policies and Programs Phase IV

Basic Information

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Modernizing U.S. Army Corps of Engineers

Planning and Regulatory Policies and Programs

Phase IV

Workshop

Designed by Leonard Shabman

Workshop Co-leader Leonard Shabman

Atlanta, GA

March 13 – 14, 2012

Workshop for regulators who must issue permits under section 404 of the Clean Water Act for municipal water supply intakes and reservoirs. Applicants for the permits include cities ranging in size from Denver and Atlanta, to smaller communities. Permitting of these large water supply facilities has become extremely controversial. The workshop identified the need for the regulatory process to more clearly state its analytical requirements, so that applicants can formulate and propose alternatives that will meet regulatory requirements.

A Water Supply Planning Vocabulary for the Regulatory Program: Report on a presentation at the "Virtual Idea Book" workshop for Corps water supply regulators, Atlanta, GA, March 13 – 14, 2012

Leonard Shabman

Resources for the Future

1. Introduction

This workshop session focused on the need for clarity of definitions to enhance communication among the regulatory agencies, the natural resource agencies and the permit applicant. The session was introduced by listing the four topics that would be covered (Figure 1). The presenter emphasized that the session should be interactive and significant discussion was welcomed and expected.

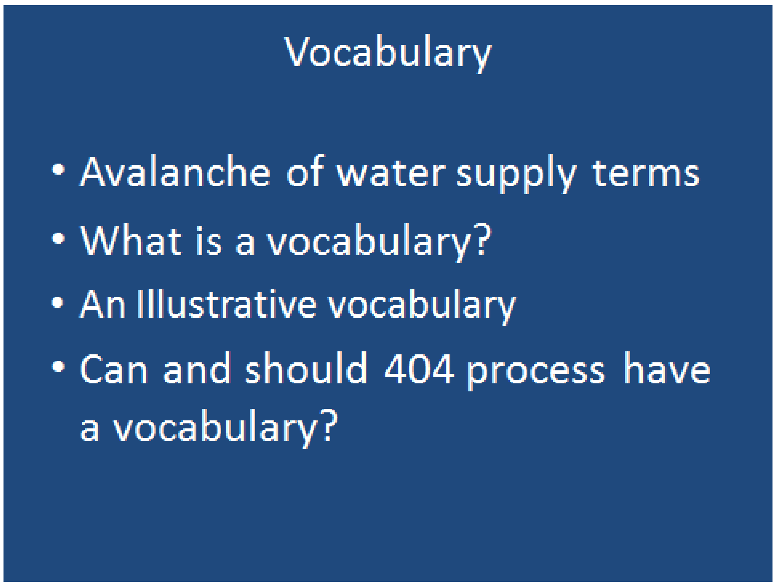

Figure 1

2. The Problem of Definition

The group was introduced to a draft IWR contract report (Figure 2). That report reviewed the analytical approaches used by state and local water agencies for assessing municipal water supply needs. The authors of the report selected a large sample of studies, and reported on how the "need" for new investments in municipal water supply was estimated. The reviewed studies were at different scales and served different purposes. Some studies were for regional plans to forecast future needs, but did not relate those needs to justification for specific projects. The needs analysis is other studies were the analytical basis for a Section 404 of the Clean Water Act fill permit application.

The IWR contract report was analyzed using "word cloud" software to create an image of the frequency of terms used in the multiple studies summarized in the draft report (Figure 3). The presentation emphasized that the report authors simply used the same terms that were used by the entities that prepared the report that was being reviewed. Apparently many of the reviewed reports did not carefully define terms and/ or the definition of the term was implied by the context in which it was used. No definitions were included in the IWR draft document and the contract authors were not obligated or expected to develop a set of terms that could be used to describe, compare and contrast the way "need" (a term that itself was not defined) was computed. What was clear, even though not explicitly stated in the draft report, is that terms are used in different ways by different entities to mean different things in water supply planning documents.

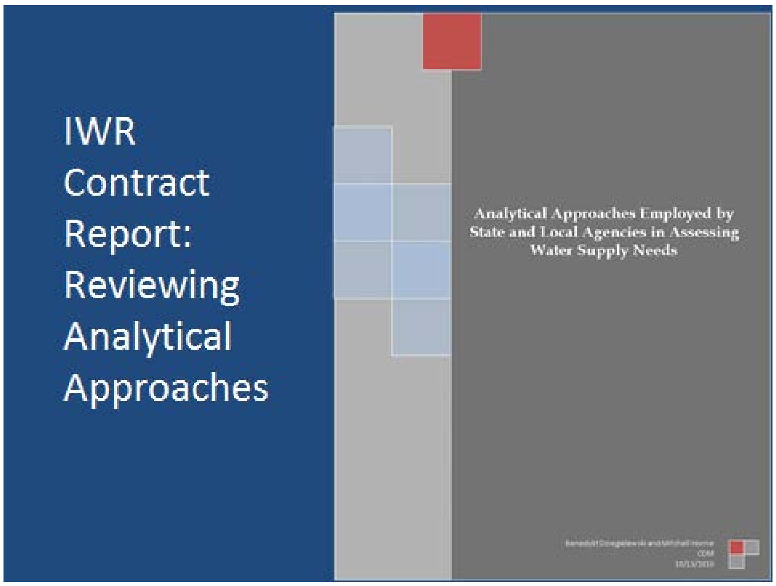

Figure 2

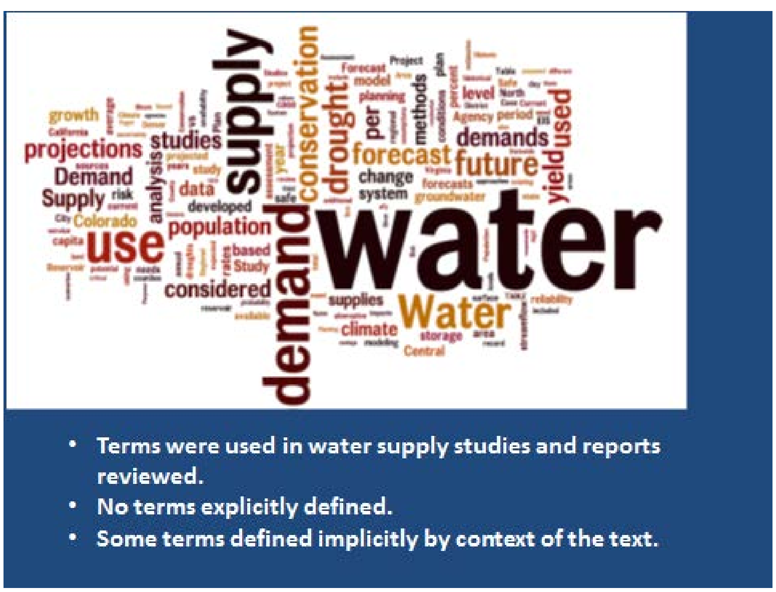

Figure 3

To motivate workshop discussion a handout (see attachment A) was provided to the group. A discussion ensued in which the group was asked to react and respond to the questions posed in Figure 4. The group concluded that all of the terms in attachment A were familiar to them, that in their experience the terms were not consistently defined and used, and that there could be a problem with inconsistent use of terms. The central problem identified is that agencies and permit applicants may be "talking past each other" with the result of wasted analytical resources and extended times necessary to reach a decision. There was a sense that there even may be disagreements among those at the workshop about what some of the terms mean. A process for reaching agreement on the meaning of terms for section 404 permitting of water supply project applications might be a useful activity.

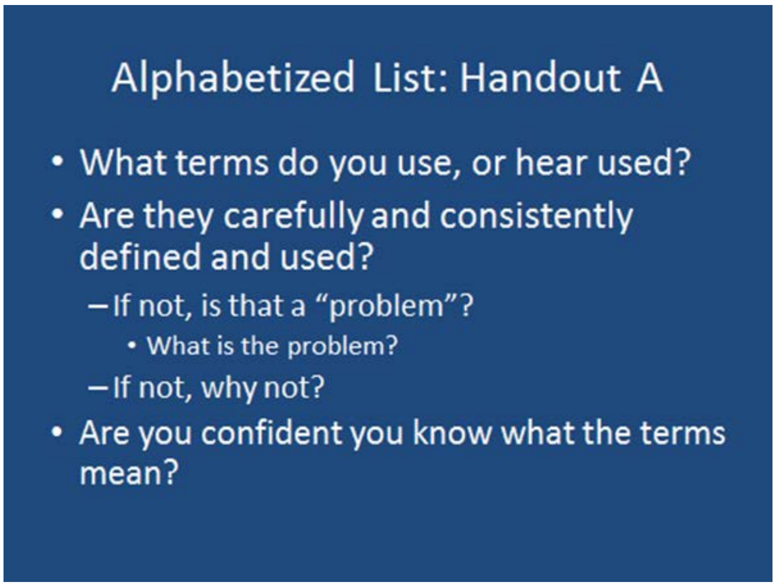

Figure 4

<u>3. Glossary or Vocabulary?</u>

The format for a vocabulary should not be confused with an alphabetical glossary. In a glossary terms are defined, often without explicit acknowledgment of the relationship of one term to the other. In that sense a glossary is analogous to a dictionary (Figure 5).

In a vocabulary terms are listed in an order that allows each definition to follow logically from, and build upon, the definitions that precede it. The motivation for a vocabulary is to not only define, but also to educate and explain. For this reason the vocabulary may include explanatory text and may include footnotes and even attachments.

The most significant result of creating a vocabulary, where each term has to have a precise and logical connection to the terms that precede and follow, is that new terms may emerge, some common terms used be redefined and some common terms may no longer appear. The presentation suggested that the process of creating a vocabulary can be a process for clarifying the analytical requirements of the 404 permit process as well as clarifying the decision criteria that will be used for permit decision making (Figure 6).

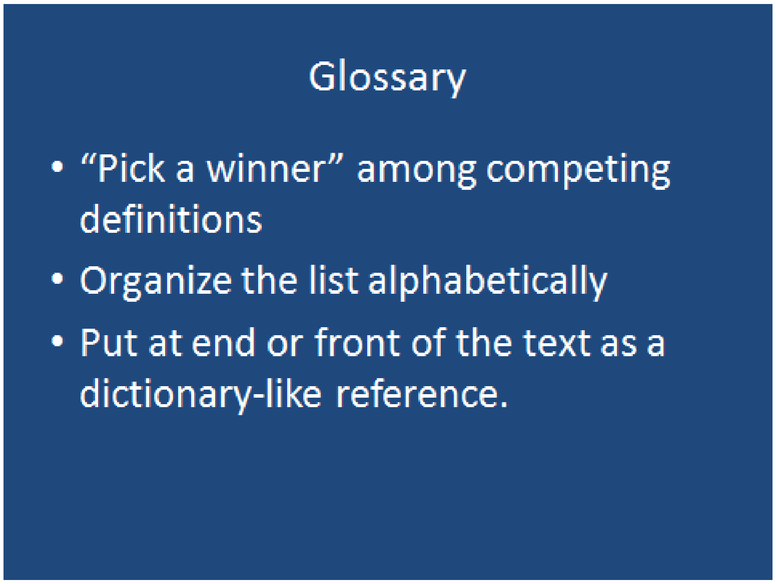

Figure 5

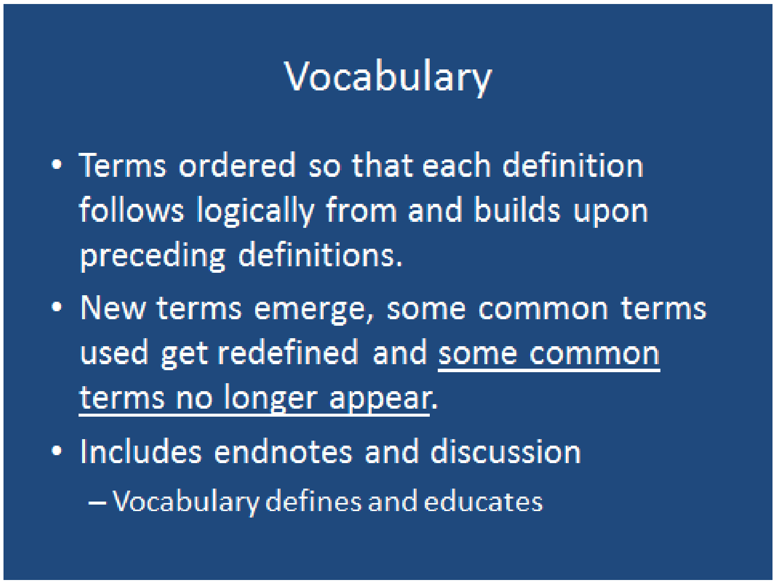

Figure 6

4. Definitions

At this point in the workshop session there was an interest in considering a process to develop a vocabulary. Since the purpose of a vocabulary is to provide definitions of key terms the next part of the session discussed "the definition of definition". This was an admittedly abstract part of the presentation, but was necessary to make the point that some terms can be defined in ways that can be "objectively" measured. Other definitions will be for terms that all would agree are "subjective" concepts. A definition of a subjective term can be understood as focusing attention on the preferences of particular decision makers (in this specific case the permitting agency, the resource agency, or the applicant) using the term (Figure 7).

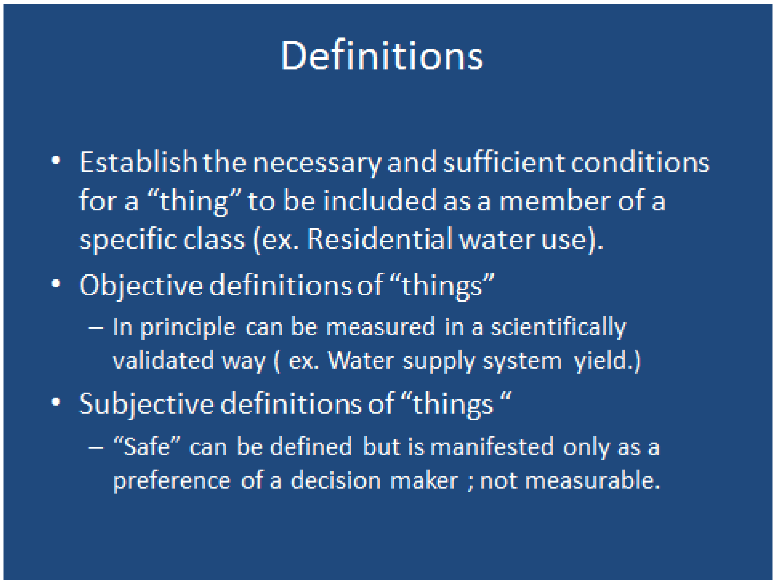

Figure 7

Figure 8 was presented so that clarifying examples could be offered. One familiar example was the use of the term safe "safe" as an adjective modifying the term "yield". In principle by using data on stream flow, pumping capacity, reservoir size, and other such variables the yield of the water supply system could be computed. If the adjective "safe" is used to modify "yield" an objective term is converted to a subjective one. As another example familiar to the workshop participants an objectively measurable term "environmental impact" can also become a subjective term "least environmentally damage". Important terms can be subjective even though they may sound objective. The obvious and relevant example is how the term "need" sounds like something which can be objectively measured, but is in fact a subjective term. How much water a municipality "needs" can only be defined once one understands the willingness of that community to accept some level of risk of customer lawns dying from lack of water or a fire department that losing pressure when trying to fight a fire.

The point made was not that a vocabulary should avoid defining subjective terms; to the contrary, to be useful a vocabulary must include subjective terms. A comprehensive and properly constructed vocabulary can reduce confusion in communication; can facilitate factual agreement about "what is" and - maybe - what might be – projections; and, can separate what is from "what ought to be", recognizing the different perspectives and obligations of the permitting agency, resource agencies and the applicant .

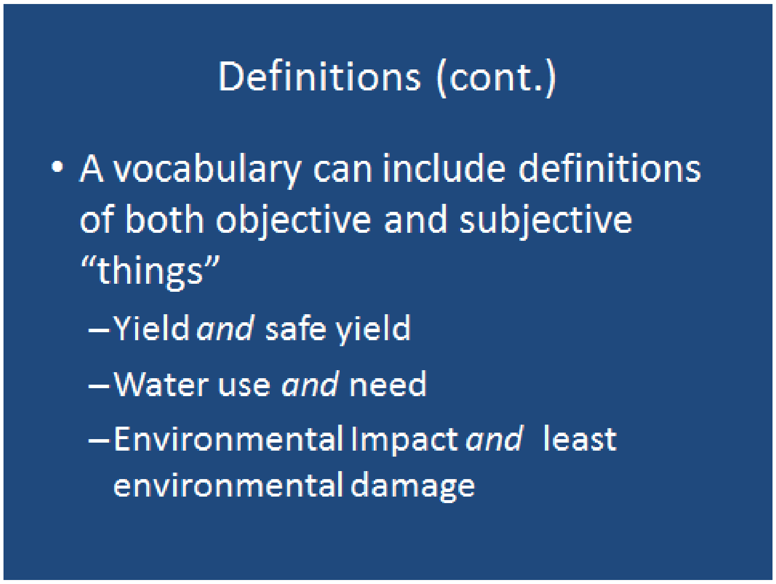

Figure 8

5. Getting Concrete: An Illustrative Vocabulary

At this point the discussion at the workshop transitioned from the conceptual to the concrete. A handout was distributed and presented to illustrate the vocabulary concept (see Attachment 2). It was stressed that other terms would need to be introduced into a full vocabulary and that in the process of introducing other terms to fill out this illustrative example may result in the definitions in the draft being rewritten. Indeed, this is the point of having a process for developing a vocabulary and as terms are defined and redefined *the very act of developing the vocabulary will help to clarify the expectations for analysis and the decision criteria that would be applied in the permit review process.*

6. Reflections on the discussion

1. If an "idea book" is going to be developed for the permitting process then development of the idea book should consider a process to develop a vocabulary. As a next step, attendees at the workshop were asked to submit suggestions for terms to be added to the illustrative vocabulary. Only one term was submitted by the deadline set at the workshop and so the vocabulary that was distributed the workshop (Attachment B) has not been edited.

2. A substantial portion of the discussion was focused on whether the US EPA needed to be included in any process for developing the vocabulary since the definitions that might be established would need to conform with EPA perspectives, or at least be accepted by EPA. In fact, this particular discussion about the vocabulary was just a manifestation of a larger discussion about the EPA role in developing an idea book.

3. The discussion frequently returned to the argument that there already were definitions of key terms and these were often established in legal rulings or in regulatory guidelines. The assertion was that those definitions were unalterable and had to be included in any vocabulary; then other terms should be built off of those unalterable definitions. The alternative view is that the vocabulary should try to accommodate existing definitions, but would not be constrained in its development by those definitions. Rather the vocabulary should first be developed so that it is internally consistent, logically constructed and advances the understanding of the analytical and non-analytical components of any "needs assessment". At that point those definitions that seem to be at odds with existing definitions could be identified and A) the vocabulary definition could be modified or B) the vocabulary definition could be proposed as a replacement for the existing definition. Concern was expressed about path B), based upon concerns about EPA reactions (see point 2 above) and about the need to hold fast to the current regulatory definition. Once again, there was an often expressed resistance to deviating from established "policy" and guidelines when constructing an idea book in general, or a vocabulary specifically.

Attachment A: Partial – Alphabetical - List of Terms Used in Water Supply Planning Reports and Studies reviewed under CDM contract

404(b)(1) Guidelines
Acceptable Level of Risk
Accuracy
Alternative
Alternative analysis
Alternatives screening
Available Supply
Avoidance
Base demand
Baseline
Benefit
Buffer
Catch All Adjustment
Climate change
Climate variability
Commercial demand
Conservation
Consumptive use
Cost
Critical Drawdown
Critical Drought
Dead Storage
Demand
Demand Area
Demand Curtailment
Demand determinants
Demand Driver
Demand Management
Demand Uncertainty
Drought
Drought contingency plan
Drought management
Drought of Record
Drought protection
Economic Effect
End Use Analysis
Environmental Impact
Expected value
Firm yield
Forecast
Forecast Uncertainty
Gap Analysis
Good Water Management Practices
Historic Hydrology
Historic Inflow
Increasing block rate pricing
Individual System
Industrial demand
In-stream flow
Interruptible Supply Contract
Just in Time Approach
Least Environmentally Damaging
LEDPA
Level of Reliability
Local Water Supply Agency
Long Term Water Conservation
Minimization
Mitigation
Need
Peak demand
Planning Horizon
Population growth
Practicable
Probablistic Shortfall Analysis
Projection
Proofing Water Risk
Purpose
Reliability
Reliability Standards
Reliability Testing
Reliable Water Supply
Requirements Based Planning
Reservoir Storage Reserve
Residential demand
Risk
Safe Yield
Safe Yield Reliability
Safety Cushion
Safety factor
Safety margin
Self Supplied Water
Sequencing
Service Area
Shortage
Shortfall
Shortfall Analysis
Simulation
Social Effect
Stationarity
Storage

Stream Flow Trace
Sustainable
Synthetic Hydrology
Synthetic Inflow
System Design
System Hardening
System load
System losses
System Reliability
Triggers
Two Part pricing
Uncertainty
Unit use rate
Water Availability
Water Consumption
Water pricing
Water Provider
Water Requirement
Water rights
Water Sector
Water Supply Needs Assessment
Water Supply Project
Water Supply Source
Water Supply System
Water Supply System Failure
Water Supply System Output
Water Supply System Performance
Water Use
Water Use Category
Water use curtailment
Water Use Efficiency
Water Use Estimation
Water use forecasting
Water Use Rate
Water User
Water Utility
Water Withdrawal
Yield

<u>Attachment B: Illustrative Water Supply Planning Vocabulary, Version prepared for and distributed at the March 13, 2012 Workshop</u>

Water provider

A private or public organization with the legal or financial responsibility to deliver potable water to its water customers (homes, businesses, community facilities, etc.) within a defined service area.

- Permit Applicant is a water provider.

Demand

The combined influence of preferences and values (green lawns and longer showers), socio-economic conditions (water pricing structure, household size, lot size, income), appliance technology and climate on the water used by water utility customer during a specified period of time.[1]

Water use

A measured volume of water delivered by a water provider to its water customers, during a specified period of time (daily, annual average, peak season, etc.)

- Can be expressed as use/ person or by different customers (use per household, use per office unit, etc.)
- May be further described by place of water use. Indoor water use is for activities of daily living such as drinking, cooking, bathing and household cleaning, in residences and businesses. Outdoor water use is for fire protection, watering lawns, washing cars, etc.

Hydrologic water supply

The temporal and spatial distribution of surface and ground water in a particular region.

- Characterization of hydrologic water supply is made using historic measures of stream flow and groundwater levels (historic hydrology) or through simulation procedures that can estimate water supply outside of the historic record.

Water supply system

A water provider's physical infrastructure, water rights and contractual arrangements that create the ability to deliver potable water to its water use customers within a defined service area for a specified period of time.

- <u>Water rights:</u> legally defined authority to withdraw water from the hydrologic water supply (a specified river, lake or aquifer, or to make use of reclaimed water) under specified conditions.

[1] Sometimes referred to as demand determinants or demand drivers.

- Contracts: legal agreements with other providers of water or with entitles having water rights (ex. Irrigation district) to transfer access to potable or non portable water to the water provider.
- Owned infrastructure: Capacity and operating rules (including drought operation plans): reservoirs, pumping stations, pipes, purification plants used to capture and deliver potable water.

Water use forecast

A prediction of the volume of water that customers of the water provider will use at some future time.

- Based on projections of the determinants of demand and how those determinants affect water use.[2]

Water supply system yield

The estimate of the specified *volume of potable water* ; that a water provider can deliver to customers *during a specified period of time* (day, week, month); *for a particular hydrologic water supply condition* (historic drought of record, simulated drought); *with a described water supply system* (existing system, system with future changes to water rights contracts, infrastructure); before the water delivery is limited to the inflows to the hydrologic water supply.

- Yield estimates will vary under different scenarios / combinations of assumptions about the italicized phrases (see: Uncertainty).
- The assumptions made may be explicit or may be implicit and not recognized.

Uncertainty

A choice situation where it is impossible to exactly describe the existing state, a future outcome, or more than one possible outcome of the choice to be made.

- Water supply planning and choice making is characterized by irreducible uncertainty when predicting future demand and water supply system yield.
- Any evaluation of future demand and water supply system yield will either explicitly or implicitly recognize uncertainty and make decisions under uncertainty.

Analytical Uncertainty:

Limited knowledge attributable to limited data bases or available conceptual and computational models.

- Some analytical uncertainty can be reduced, at the cost of time and $, with more study. For example, there can be more study of how a juvenile fish species will be affected by a water intake, or test wells might better define the structure and water holding capacity of an aquifer.

[2] Can be simple or complex projection method. There is no assurance that more complex methods will prove more accurate with hindsight.

- Some analytical uncertainty is unavoidable. For example, predicting the socio economic profile of a community be in 30 years).

Socio economic system uncertainty

The influence of factors outside of the water provider's control that lead to changes in customers' demographic and economic profile, water using technology, preferences, etc.

Institutional System Uncertainty

Future institutional conditions that may affect the operation of the current water supply system or ability to expand the water supply system.

- Can include uncertain future budget allocations, future regulatory and water rights changes, future permitting cost, delay and decision rules.

Natural System Uncertainty

The "true" future state of a natural systems, and the result of alterations to those systems, can only be characterized by a probability distribution of environmental services flows (see: Environmental damage).[3]

- Some might want to analytically assign probabilities to this source of uncertainty. Frequentist or Bayesian statistical methods bound, but do not eliminate, uncertainty.

Water Supply Scenario

A particular combination of assumptions made about future determinants of demand, hydrologic water supply and the water supply system.

- The number of permutations and combinations of assumptions (i.e. scenarios) is infinite in a mathematical, but not logical sense. This means that judgment will be used to build only plausible scenarios.
- Many of the disputes that occur are disputes about the plausibility of the assumptions that are used to build the scenarios. However, what is plausible to the water provider seeking a permit may not seem plausible to others. Effective conflict management will seek to narrow the number of scenarios to a few that all can agree have some degree of plausibility, in recognition of all sources of uncertainty.

Shortfall Analysis (a.k.a. shortage)

A calculation of difference between a) forecasted water use for a specified period of time (day, month, quarter, year) and b) the water supply system yield, under a range of different scenarios.[4]

[3] These may be open and chaotic systems and not subject to being described in probabilistic terms.

[4] May be assigned a likelihood using statistical methods and expert judgment.

Safe Yield

A specific scenario about hydrologic water supply, future determinants of demand, and the water supply system that results in reliable delivery of potable water (See: Water supply system relaibaility).

- The definition of safe yield of the current water supply system is the basis for the formulation and evaluation of alternatives to assure safe yield over a specified planning period.

Need

The USACE regulator's determination of the current safe yield for which alternatives for future water supply system reliability should be formulated.

- May differ from applicant's safe yield, based on the selection of a different scenario as the most plausible. [5]

Alternative

A combination of *practicable* measures predicted (see: Uncertinaty) to eliminate the shortfall (secure safe yield) under each scenario.

> <u>Water use management</u>
>
> Programs to influence the determinants of demand in ways that reduce water use on a permanent basis (conservation [6]) or temporary basis (drought contingency measures).
>
> <u>Expanded infrastructure</u>
>
> <u>Dual Water distribution system</u>
>
> <u>Regional System interconnection contracts</u>
>
> <u>Water rights acquisition</u>

Practicable Alternative

An alternative that includes only measures capable of being implemented.

- Practicable describes an action that it is possible to accomplish. Synonym for practicable: feasible.

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[5] Analysis can help to bring about agreement / understanding of the plausibility of the different scenarios. The question for the regulator is "what do I have to believe to believe the assumptions that constitute any scenario?

[6] Incentives or regulations for changing outdoor landscaping to reduce the need for outdoor irrigation; Incentives for homeowners to invest in more efficient appliances and water fixtures

- In the context of water supply xeriscaping to replace all lawns; encouraging homeowners to not flush after urination or mandating composting toilets would reduce water use, but may not be deemed practicable by a water provider. However, others may deem one or more of these actions practicable if accompanied by regulation and incentives; the water provider may not deem those regulations or incentives practicable.

Water supply system reliability

A reliable water supply system is one that reduces the *expected* [7] adverse consequences for water provider's customers to acceptable levels. Adverse consequences include a) high frequency of temporary water use restrictions, b) larger costs for a future increment of capacity versus expanding today, c) expected high permitting costs and limited options for a future water system expansion, d) inability to become a wholesale water provider to surrounding communities, e) water supply safe yield as an impediment to community growth.

Preferred Alternative

The alternative that a permit applicant (water provider) expects will assure water supply system reliability over a specified period of time, within a *practicable* cost and rate structure.

- For example, incurring the costs for some incremental amount of storage capacity in a reservoir would be justified to the applicant if they wanted to avoid the adverse consequence (that is, increase reliability) and avoid having to implement drought contingency measures on a frequent basis.
- Related is the desire to create, as opposed to respond to, the future. For example, the desire may be to create large capacity to deliver water in a region in order to foster growth or become a wholesale seller of water (these kinds of purposes might find its ways into use projections.[8]

Environmental Damage

The loss of ecosystem / watershed services, relative to current service levels, that results from a change in watershed structure and function attributable to implementation of an alternative.

- Watershed structure and function: quality weighted wetland area; stream hydrograph; river connection to flood plain, etc.
- Ecosystem / watershed services: populations of specified species; waste assimilation.

[7] Uncertainty and scenarios are embedded in the "expectation"

[8] Whether this will be the outcome of the supply expansion is uncertain

LEDPA

The smallest loss of ecosystem services from among a set of *USACE-defined* practicable alternatives that result is a *USACE-defined* reliable water supply.

- This may or may not be the preferred alternative of the applicant. Differences can result from a) different views on what measures are practicable, b) different definition of what constitutes a reliable water supply system and c) different understanding of and willingness to incur costs to avoid environmental damage. [9]

[9] The costs of avoiding environmental damage as well as the adverse consequences of a less reliable system are borne by the customers of the water provider.

Leonard Shabman and Paul Scodari

Towards Integrated Water Resources Management:

A Conceptual Framework for U.S. Army Corps of Engineers

Water and Related Land Resources Implementation Studies

Visiting Scholar Report 20112-VSP-01

Institute for Water Resources

February 2012

http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/2012-VSP-01.pdf

Visiting Scholar Program

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Towards Integrated Water Resources Management

A Conceptual Framework for U.S. Army Corps of Engineers Water and Related Land Resources Implementation Studies

2012-VSP-01

US Army Corps of Engineers®

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Visiting Scholar Program

Throughout its history, the Institute for Water Resources (IWR) has invited preeminent water resources academicians and practitioners to take up residence at the Institute to foster scholarly exchange. At any given time, IWR frequently has faculty from universities spending time in residence at the Institute. Both IWR and the Corps benefit from such faculty engaging in ongoing water resources studies and research on a reimbursable basis. Visiting scholars are expected to help infuse new energy and ideas to the IWR program, while the practical work environment at IWR and/or the Hydrologic Engineering Center (HEC) provides a stimulating context for mutual exploration of potential advances in hydrologic engineering and planning analysis. Such experiences have proven to be intellectually invigorating for both the Institute staff and the visitors themselves.

American Association for the Advancement of Science
Science and Technology Policy Fellows Program
Through the American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellows Program, IWR sponsors post-doctoral and senior fellows to work on water resource policy issues such as analyzing the linkages between water resources development and water resources problems (e.g. drought, floods) and the economies of developing nations. Individuals with a systems engineering, economics, public participation or water resources background are especially encouraged to apply. This highly selective fellowship program gives scientists and engineers a real-world introduction to how science interacts with policy in Washington.

Leo R. Beard Visiting Scholar Program
For many years, the Hydrologic Engineering Center (HEC) has invited prominent hydrologic and hydraulic professionals to take up residence at HEC in Davis, CA to foster scholarly exchange. Faculty from a number of universities have spent some of their sabbatical with HEC and on occasion HEC has also had prominent engineers from other agencies join the Center in the same capacity. The experience and the exchange of ideas that these scholars bring to HEC have proven to be intellectually satisfying and productive for both HEC staff and the visitors themselves. Such scholars in residence are known as "Leo R. Beard Visiting Scholars."

Maass-White Visiting Scholar Fellowship
The Maass-White Visiting Scholar Fellowship is designed to ensure that today's water resources challenges benefit from innovative thinking of the nation's top academics, and to promote a deeper understanding of real-world water resource problems by those in academia. The fellowship honors the late Arthur Maass and Gilbert F. White–two scholars who had a revolutionary impact on the practice of water resources planning and management.

National Research Council Research Associateship Program
Through the National Research Council (NRC) Research Associateship Program, IWR sponsors postdoctoral and senior research awards to conduct relevant research for one to two years at one of IWR's locations. Fellowships are given for the purpose of conducting research (chosen by the doctoral level scientists and engineers) to apply their special knowledge and research talents to areas that are of interest to them and to the host laboratories and centers.

UCOWR Water Resources Fellowship
The Universities Council on Water Resources (UCOWR) and IWR developed a visiting scholar program in 2003. The program invites academicians to the Institute to focus on emerging water resource issues of relevance to the civil works mission. While on sabbatical these scholars are expected to perform applied, policy-relevant research to extend the Corps of Engineers knowledge of and thinking about emerging water resources needs and issues. UCOWR Fellows, chosen via a UCOWR/Corps panel, are university professors who have substantial applied experience in water resources planning and management, as well as strong teaching credentials.

Lieutenant General Frederick J. Clarke Fellowship
Lieutenant General Clarke (Chief of Engineers 1969-1973) was instrumental in securing expert, independent advice on environmental issues facing the Corps by founding the Environmental Advisory Board (EAB). The Corps plays an increasingly important role in many of the most profound environmental issues faced by our nation's water resources. The Clarke Fellowship recognizes that USACE will need the advice of our nation's brightest scholars to ensure that these environmental issues are tackled with the utmost skill and understanding. The fellowship provides scholars with the opportunity to engage with and advise USACE leaders on important policy issues related to their environmental mission. Clarke Fellowships are awarded to researchers who have demonstrated scholarship in the areas of environmental quality and policy analysis in water resources planning.

Visiting Scholar Program

February 2012

Towards Integrated Water Resources Management

A Conceptual Framework for U.S. Army Corps of Engineers Water and Related Land Resources Implementation Studies

2012-VSP-01

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This report does not reflect policy development by the U.S. Army Corps of Engineers, and its publication does not represent any official position or policy of the Executive Branch, Department of the Army, U.S. Army Corps of Engineers, or IWR, nor does it imply any endorsement of the report contents by those entities. The report reflects the views of the authors alone and is written in the form and structure of current Corps planning guidance in order to help readers to identify how and where IWRM principles could be woven as an integrated process into the Corps planning framework.

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Motivation and Purpose

The U.S. Army Corps of Engineers (Corps) has long been required to demonstrate that its proposed water resource development projects provide net benefits to the nation as a condition for Congressional authorization and funding. The Corps was instructed by the Rivers & Harbors Act of 1902 to show in project planning studies that recommended water resources investments produced benefits that exceeded costs. This general principle was famously reiterated by the Flood Control Act of 1936, which stated:

> "It is hereby recognized that destructive floods upon the rivers of the United States, upsetting orderly processes and causing loss of life and property, including the erosion of lands and impairing and obstructing navigation, highways, railroads, and other channels of commerce between the States, constitute a menace to national welfare; that it is the sense of Congress that flood control on navigable waters or their tributaries is a proper activity of the Federal Government in cooperation with States, their political sub-divisions and localities thereof that investigations and improvements of rivers and other waterways, including watersheds thereof that for flood-control purposes are in the interests of the general welfare; that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries including watersheds thereof, for flood-control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected."

Since that time there have been multiple efforts to interpret the Congressional intent within Corps guidance for project planning studies. Perhaps the greatest challenge has been to reflect the concept of multiple objectives (as alluded to in the quotation above) in plan formulation and evaluation. This was a major focus of the Harvard Water Program in the 1960s, and its ideas for multi-objective planning were manifested in Corps planning guidance in the early 1970s under the so-called *Principles and standards for planning water and related land resources*. However, subsequent federal water planning guidance set out in the 1983 *Economic and environmental principles and guidelines for water and related land resources* (P&G) moved away from a multiple objective focus by defining a single federal objective based on national economic development, subject to an environmental protection constraint.

Since publication of the 1983 P&G planning framework, the Corps' role in water resources planning and management has continued to evolve in response to changing public values and program budget levels and priorities, and the cost sharing reforms of 1986. The Corps has made significant changes to modernize its internal plan formulation and evaluation procedures and analytical methods. Perhaps most significant was the creation of planning and analysis procedures to implement a new ecosystem restoration mission, to accompany the Corps' historic responsibilities for enhancing waterborne commercial transportation and flood and coastal storm damage reduction.

Today, the concept of "Integrated Water Resources Management" (IWRM) is being advocated as a better way to approach the challenges of 21st century water management, and many observers have noted that current Corps planning guidance falls short of that ideal. The so-called Section 216 reports from the National Research Council noted the need to re-focus attention in planning studies to multiple objectives and tradeoffs, better account for uncertainty, and accommodate the concepts of adaptive management, stakeholder collaboration, and systems analysis for watershed scale planning and evaluation. Recent literature on "ecosystem services" provided by the natural environment has been offered as yet another concept to be considered in Corps planning. These planning concepts and more are encompassed by the principles of IWRM.

To facilitate movement toward an IWRM focus in Corps planning studies, a conceptual framework is needed that will allow the Corps to review, and as needed modify and extend, its current practices and then organize those practices according to IWRM principles That framework must also accommodate the reality that the Corps remains bound by the particular ways its studies and projects are authorized and funded, which not only circumscribe the missions of the agency, but also affects the ways in which modern planning concepts can be accommodated in plan development and implementation. This framework is offered in order to stimulate discussion and further dialogue on how contemporary concepts of IWRM might be integrated into Corps planning.

The framework contained in this report is written in the form and structure of current Corps planning guidance in order to help readers to identify how and where IWRM principles could be woven as an integrated process into the current Corps planning framework. The conceptual framework was prepared by Leonard Shabman, Resident Scholar at Resources for the Future and Visiting Scholar at the Corps' Institute for Water Resources (IWR), and Paul Scodari, IWR Senior Economist.

Some Reflections on the Framework

Among the most important challenges faced in revising Corps planning and analysis guidance to reflect contemporary concepts of IWRM are the following:

1. The need for the planning framework to recognize and accommodate the authorized Corps missions and policies (e.g., cost sharing requirements of non-federal project sponsors) that would remain unaffected by any changes to the planning process.

2. The need to better acknowledge and communicate the uncertainties inherent in the analyses that support water resources investment decisions, including possible recognition of multiple possible future "without project conditions."

3. The need to clearly define the Corps' role in ecosystem restoration relative to that of other federal and non-federal agencies.

4. The need to clarify the Corps' role in flood risk management relative to that of other federal and non-federal agencies.

5. The need to recognize that multiple decision criteria measured in non-commensurate terms (monetary units, non-monetary quantitative units, and qualitative descriptions) and shared decision-making means that plan selection cannot be determined by applying an analytical algorithm that, through computation, identifies the "best" plan.

6. The enhancement of collaborative planning and shared decision-making will be realized by a) incorporating different agency responsibilities in plan formulation, b) increasing the transparency of the logic and computations in the analysis, and c) assuring that multi-criteria evaluation and

analytical tools (such as monetization of project effects) contribute to reconciliation of disparate views and lead to more expeditious decision-making.

Of particular note is that all of the challenges are treated within the framework as an integrated process as opposed to being addressed as isolated subjects. In fact, the imperative was to have a framework that incorporated the many individual planning concepts central to IWRM, not as a list of considerations, but rather as part of an integrated whole that recognizes interdependencies and has a consistency of definitions. As one example, the framework relates the definition of adaptive management, and where that concept applies in plan formulation, to the ways that uncertainty is addressed in the planning process.

Incorporating IWRM concepts, especially for complex water resources problems, would add to the requirements of a planning study at the same time that there are demands on the Corps for shorter-duration and less-costly studies. Any further development of the conceptual framework must accommodate the need to reconcile the level of detail required by the framework with study time and resource constraints.

Finally, new imperatives for collaborative planning will highlight, not mask, differences among decision participants in the identification of planning problems, opportunities, and preferred solutions. This in turn will highlight differences of view about the meaning of the federal interest and how multi-objective plan formulation and multi-criteria evaluation can be used in federal budgeting decisions and financing responsibilities for the different actions included in a preferred alternative. At the same time, the collaborative planning requirements may demand a new set of skills and new decision processes throughout the Corps hierarchy.

Request for Comments

The conceptual framework is being published as part of IWR's Visiting Scholar Program in order to stimulate thoughtful dialogue and to facilitate the exchange of ideas relevant to integrating contemporary concepts of IWRM into civil works planning guidance and practice. Corps staff, other federal agency and non-federal agency staff, and the general public are asked to share their observations and insights on any part or the entirety of the framework. Submitted comments can relate to the clarity, substance, or workability of the framework or parts thereof. Comments should be submitted electronically to Paul Scodari (paul.f.scodari@usace.army.mil).

In doing so, please note that the publication of this report by IWR does not represent any official policy, position, or endorsement of the report contents by the Executive Branch, Department of the Army, Army Corps Engineers, or IWR.

In reviewing the framework and in consideration of this request for comments, the following additional factors should be kept in mind. First, there is more conceptual thinking behind many sections of the framework than can be fully elaborated on within the framework. Some of that thinking is partially reflected or at least alluded to in the explanatory endnotes as well as in the two issue papers included in the appendices. Therefore, readers are encouraged to consult the framework endnotes and appendices when reviewing the document.

Second, the framework is intentionally Corps-centered, and it is recognized that some have argued that Corps planning need not be constrained by authorized Corps missions and administration budget priorities. Whatever the conceptual merits of this argument, the authorized Corps mission areas need to be highlighted, and the limits of Congressional authorization and the reality of cost sharing with non-federal project sponsors need to be accommodated.

Third, the framework focuses on project level planning, but within a watershed context. The Water Resources Planning Act of 1965, which created the authority for the existing P&G, draws a distinction between Level C (project) and Level B (basin scale) planning. Level C planning is what is addressed by the framework. Programmatic authorizations are more like Level B studies in that they establish the broad guidelines for the Level C planning and project implementation; the programmatic regulations of the Comprehensive Everglades Restoration Plan are an example of how that relationship might work. The possible contribution of this framework to programmatic planning and implementation (a blend of level B and C) has not been addressed here, but could be as logical future actions.

Finally, trends in the relative share of the Corps budget dedicated to construction-general versus operations and maintenance, combined with aging Corps-managed infrastructure and increasing attention to project re-operation and modifications to address emerging problems and opportunities (e.g. sustainable rivers program, water supply reallocation), mean that Corps planning guidance will increasingly be applied to modifications of existing projects as well as to project operations and management. This will increase the need for attention to collaborative planning, because recommended changes will need to take into account and secure agreement from the stakeholders served by the current project operations as well as the beneficiaries of the outcomes associated with potential changes in project operations.

This report should be cited as follows:

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Towards Integrated Water Resources Management: A Conceptual Framework for U.S. Army Corps of Engineers Water and Related Land Resources Implementation Studies

Section 1. Introduction

a. Purpose. This framework is for use by the U.S. Army Corps of Engineers (Corps) in formulating, evaluating, displaying, comparing, and recommending alternative plans in water and related land resources implementation studies. It is to be applied to project-level study authorities for the purpose of determining the federal interest in new and modified water resources investments and operations.

b. Planning resources. This framework requires the practical application of contemporary planning and analytical procedures in hydrology, engineering, economics, planning, the biological sciences, and other natural and social sciences for plan formulation, evaluation, and comparison within the civil works missions and authorities of the Corps.

c. Planning guidance. For purposes of conducting implementation studies, the Secretary of the Army will issue Corps-specific guidance on analytical procedures that that will implement this framework in consideration of:

- Available study times and resources,
- The level of detail in the study reports required for informed decision-making at all levels of the decision hierarchy, and;
- The need to assure the transparency of the analysis to non-federal sponsors and other agencies and stakeholders, and assure their engagement in the planning process at appropriate junctures.

Section 2. Federal Interest Evaluation Criteria

2.1 Primary Evaluation Criteria

The following effects of alternative plans shall be evaluated and used as primary federal evaluation criteria in plan display, comparison, and decision-making:[1]

a. National environmental quality (NEQ) effects. NEQ effects represent the positive and negative changes in the physical, chemical, and biological conditions of the nation's water and related land resources at the watershed scale, as measured in non-monetary units. [2]

b. National economic efficiency (NEE) effects. [3] NEE effects represent the positive and negative changes in the economic value of water and related land resources[4] or the economic value of the national output of goods and services produced using these resources, as measured in monetary units.

2.2 Additional Evaluation Criteria

The following effects of alternative plans will be evaluated and reported as additional federal evaluation criteria in plan display and comparison. The District Engineer may determine that one or more of these additional evaluation criteria are neither applicable nor material for decision-making, but must provide a statement in the report justifying that determination.

a. Public safety effects. These effects represent the effects of flood and coastal storm damage reduction plans, as well as other types of plans when warranted, on the reduction of and remaining risks to human life and safety, as measured in non-monetary units and/or qualitative descriptions.

b. Other environmental quality effects. These effects include effects on significant cultural and aesthetic resources, as well as sub-watershed-scale ecological resources, as measured in non-monetary units and/or qualitative descriptions.[5]

c. Effects on low-income, tribal and minority communities. These effects include the incidence of national economic efficiency effects, national environmental quality effects, public safety effects, and other environmental quality effects—as measured in the units for these evaluation criteria outlined above— on low-income, tribal, and minority communities. These effects also include any employment and income effects on these population groups, as measured in monetary and non-monetary units.[6]

Section 3. Overview of Planning Process

3.1 Introduction

The planning process consists of a series of iterative elements to identify problems and opportunities, to formulate and evaluate alternatives as combinations of water and related land resource management measures that are reasonably expected to address the problems and opportunities, and to display and compare the results of the evaluations of alternative plans. The product of the planning process is analysis and communication of the significant effects of each alternative plan with clarity and transparency sufficient for decision participants and decision-makers to be fully aware of the assumptions employed, the data and information included in the analysis, and the reasons and rationales for their use in analysis.

a. Planning elements. The planning process includes the following analytical elements in support of decision-making:

(1) Specification of the water and related land resources problems and opportunities relevant to the planning setting.

(2) Inventory, forecast, and analysis of current and expected future water and related land resource conditions (that are relevant to the identified problems and opportunities) within the planning area if no Corps civil works action is taken (the future, without-project condition).

(3) Formulation of alternative plans to alleviate problems and realize opportunities.

(4) Evaluation of the effects of the alternative plans on the problems and opportunities and on the federal evaluation criteria, as compared with the without-project condition.

(5) Display and comparison of significant effects of alternative plans to facilitate the selection of a preferred plan.

(6) Recommendation and reporting of a preferred plan

b. Iterative Process. Planning is a dynamic process requiring iteration among the five planning elements that engages all the technical specialists and analysts, those responsible for decision-making, and other relevant agencies and stakeholders. This iterative process may sharpen the planning focus or change its emphasis as new data are obtained or as the specification of problems or opportunities change or become more clearly defined. Consideration of each element in the process may require previous elements to be revisited.

c. Planning results. The study report that recommends a plan that would require Corps budgetary support or changes to existing project operations must a) justify the plan using the analysis of the plan according to the federal evaluation criteria, and b) provide assurances that any measures in the plan that are to be implemented by non-Corps entities (public or private) will be undertaken by those.

3.2 Scoping

There needs to be an early and open "scoping" process as soon as practical after a decision is made to begin planning. This process is complementary with the scoping process described in the CEQ NEPA regulations (40 CFR Parts 1500-1508).

The purpose of scoping is to obtain the perspectives of other agencies and stakeholders and to consider those perspectives in preparing a study plan that identifies a clearly understood and broadly supported focus and scope of analyses to be undertaken in support of decision-making, and ensure that all significant decision-making factors are addressed while avoiding unneeded and extraneous studies. (Section 3.2.1.e. describes the engagement of non-Corps parties in the planning process.)

3.2.1 Major Scoping Factors

Major factors to be addressed in scoping include: planning purpose, planning area, analytical focus and level of detail, accommodation of uncertainty, and engagement with other agencies and stakeholders in planning.[7]

a. Planning purpose. Planning purpose refers to the water resources management problems and opportunities to be addressed in a planning study. The starting point for identifying the planning purpose(s) is the study's authorizing document, which normally identifies in general terms the area-specific problems and opportunities for study. While there may be a wide range of potential water-related problems and opportunities in any planning area, the Corps must necessarily focus its planning around those problems and opportunities that are consistent with Corps authorities and priority missions.

b. Planning area. The planning area refers to the specific geographic area where alternative plans to address problems and opportunities are formulated and evaluated. The planning area should include the geographic scope necessary for analyzing the nature and extent of problems and opportunities, as well as potential locations of alternative management plans to alleviate problems and realize opportunities (often called "project areas") as well as the locations of resources and existing projects that would be directly, indirectly, or cumulatively affected by, or that could affect, the alternative plans (often called the "affected area").

   A systems perspective should be taken to define the planning area.[8] The planning area should be of sufficient size to permit the assessment and evaluation of the hydrologic interactions of a project with other water resources projects and programs. The 8-digit Hydrologic Unit Code should be initially used as the appropriate watershed scale,[9] but planners should assure that the planning area includes potential significant hydrologic interactions of plans with existing civil works projects in other watersheds.

   In some cases, considerations other than hydrologic interaction may contribute to defining the planning area. For example, the planning area associated with inland navigation waterways and related harbors are likely to include the regional transportation sector, including alternate and complementary modes of transportation as well as directly related harbors. As another example, if a wildlife species of interest is identified for management, the relevant eco-region that defines the species habitat throughout its life cycle may not coincide with watershed boundaries.

c. Analytical focus and level of detail. In general, the focus, methods, and level of detail and complexity of planning analyses should be commensurate with the scale, scope, and magnitude of problems and opportunities and expected management effects, budget costs, analytical uncertainties, and levels of stakeholder conflict that might be expected to attend a potential decision. At the same time, the level of detail and complexity in planning analyses must necessarily be scaled to match the available study resources.

d. Addressing uncertainty. An important part of scoping is an initial determination (subject to later revision) of how uncertainty will be addressed in planning.

   Uncertainty is the result of imperfect knowledge concerning the present or future state of a system. The concern with uncertainty in civil works planning relates to the "cost" of decision error—that is, while a decision today will be made with the expectation of positive future outcomes, there is the possibility that the decision may prove to have unacceptable future adverse consequences. Adverse consequences are often thought to include, although not limited to, undesired ecosystem changes, loss of human lives, property damages and income losses. In a broader context, adverse consequences also include the commitment of current resources that may not achieve intended results (e.g., navigation investments undertaken today may not realize the projected transportation cost savings because the anticipated increased future navigation traffic never materializes; or actions taken to modify the future structure and functions of an ecosystem may not yield the intended biological outcomes). Therefore, it is not uncertainty itself that is the concern; rather, the concern is about the magnitude of possible future adverse consequences (i.e., costs) from a decision. Two basic sources of uncertainty are:

(1) Knowledge uncertainty. Knowledge uncertainty refers to the confidence in an analytical prediction of a future state of some system. Knowledge uncertainty arises from incomplete understanding of a relevant system as well as modeling and data limitations. Some knowledge uncertainty is reducible in principle with more data and the development of more complete models for data analysis and prediction. However, reducing knowledge uncertainty may require greater costs and time than is available to the study.

(2) Natural variability**.** There is inherent variability in the physical world and this "randomness" is irreducible. In the water resources context, uncertainties related to natural variability include phenomena such as stream flow, assumed to be a random process in time, or soil properties, assumed to be random in space. Natural variability cannot be altered by obtaining more information, although its characterization might improve with additional knowledge. Natural variability is sometimes dealt with by statistical or probabilistic methods. [10]

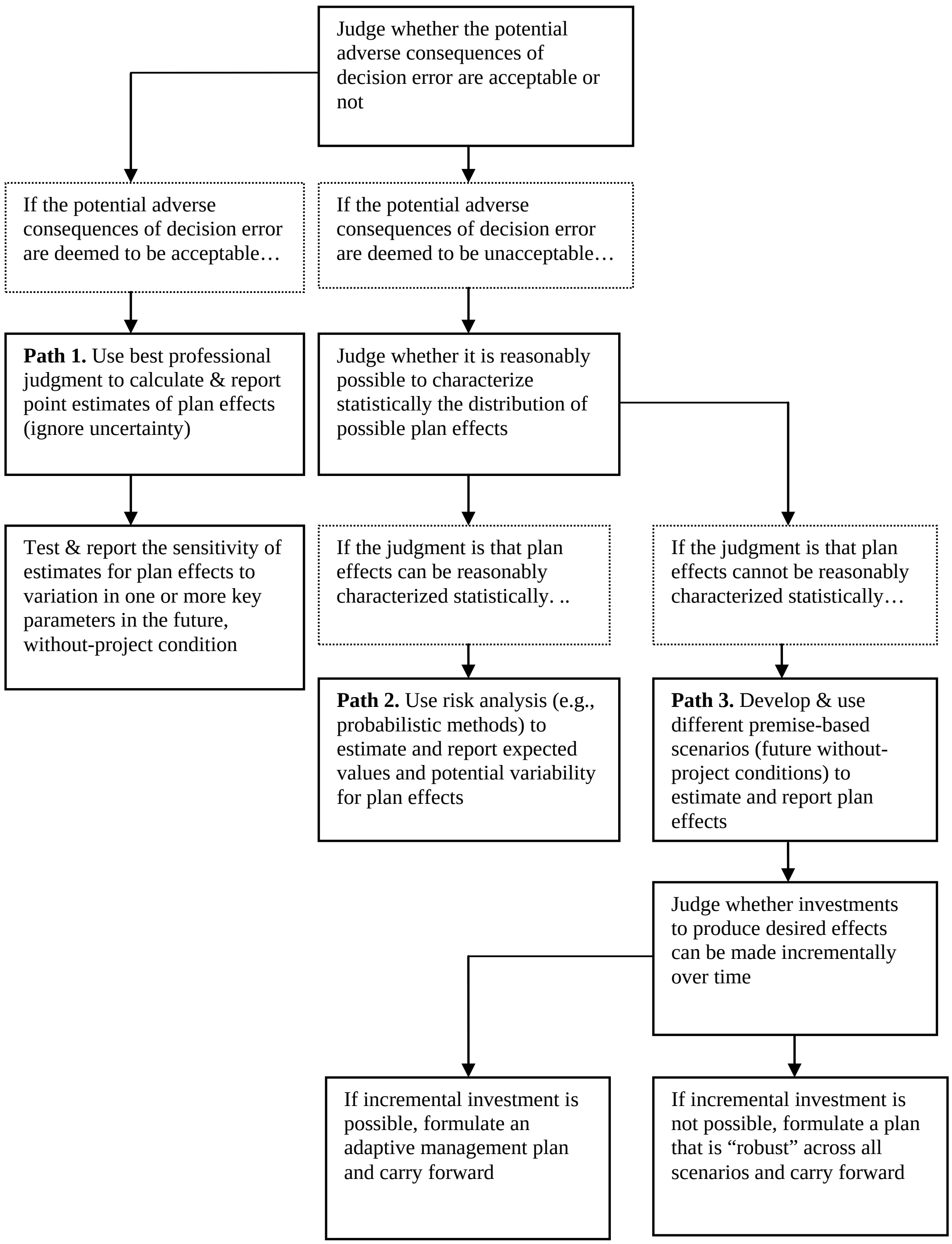
   Figure 3-1 illustrates three different paths for addressing uncertainty in planning, and at the scoping stage one path will be selected. As part of the scoping process, and as one basis for choosing a path, an inventory will evaluate the quantity and quality of models and data required for specification of identified problems and opportunities, for forecasting with- and without-project conditions, for identifying potential alternatives for addressing the problems and opportunities, and for evaluating alternative plans. While an initial scoping decision will select one path (in consideration of the necessary level of analysis detail, available resources, and available data and models), at any point in the iterative planning process a decision may be made to shift from the initially chosen path for addressing uncertainty to another path. The District Engineer (DE) in the final report must provide a statement justifying the path chosen.

Path 1: When there is little uncertainty or when the potential future adverse consequences of making a wrong decision are judged to be acceptable, then each planning element will be executed using **best professional judgment** for making point estimates of without-project conditions and with-project plan effects on problems, opportunities, and the federal evaluation criteria.[11] This could be augmented by using sensitivity analysis to identify how estimates of plan outcomes would change with variation in one or more key parameters relating to the estimated future, without-project condition.

Path 2: If the potential adverse consequences of decision error are judged to be unacceptable, but the distribution of possible plan outcomes can be reasonably characterized statistically with available study resources, planning should employ a **risk analysis** framework. Risk analysis will assign probabilities to possible future conditions and outcomes using expert elicitation or statistical data analysis, and report the range of possible outcomes and their likelihoods for the without-project conditions and with-project plan effects on problems, opportunities, and the federal evaluation criteria.

Path 3: If the potential adverse consequences of decision error are judged to be unacceptable, and the level of uncertainty makes it impossible to credibly characterize the statistical distribution of possible plan outcomes, planning should build **premise-based scenarios** for reporting without-project conditions and with-project plan effects on problems, opportunities, and the federal evaluation criteria. [12] A decision to employ scenario analysis to address uncertainty might be made during the scoping phase, or might come later in the planning process when it becomes apparent that uncertainty has important implications for plan formulation, evaluation, and decision-making. Under such conditions of uncertainty, if there are opportunities to formulate a plan that approaches problems and opportunities with incremental implementation, then adaptive management measures can be included in one formulated alternative. Conversely, if there is no opportunity for incremental implementation, the analysis should report how different alternatives address problems and opportunities and contribute to the federal evaluation criteria under different scenarios. [13]

Figure 3-1: Scoping for Addressing Uncertainty in Planning



e. Engagement with other agencies and stakeholders. As part of the iterative process, other agencies and stakeholders may be engaged to help inform the specification of problems and opportunities, engage in joint fact-finding, suggest alternative plans, and participate in the formulation, evaluation, comparison, and recommendation of alternatives. The Corps will engage with other agencies and stakeholders in different ways depending on project circumstances. The degree of engagement varies from holding public meetings to full integration of stakeholder involvement into each step of the planning process.[14]

(1) Parties to engage

a) Cost share partners. Those non-federal agencies or other legal entities that are legally obligated to participate in plan development or provide funds or in-kind support for plan development or project implementation must be engaged in the planning process.

b) Other federal and non-federal government agencies. Civil works projects and their operations have limited capacity to alleviate problems and realize opportunities on their own. Whether in the area of flood damage reduction and risk management, reliable water supply, or ecosystem restoration, the authorities of the Corps are either limited (as in the areas of water quality improvement, urban river restoration, and floodplain regulation) or there are other agency programs that can bring expertise and funding to the development of alternatives (e.g., FEMA). The completeness criterion (which is addressed later in this framework) demands attention to including other agency program measures in plan formulation. However, there are often differences in program missions and the analytical approaches and decision criteria used among the Corps and other agencies. Engagement with other agencies (both federal and non-federal) that are not cost share partners in the scoping process will increase the understanding of their respective programs and allow for consideration of those programs in plan formulation.

In addition, interagency engagement will allow agencies with different missions and responsibilities than those of the Corps to participate (see options for engagement) in plan formulation. Such participation will recognize a broad range of interests with the potential to formulate and recommend a plan that will minimize opposition to plan implementation.

c) Other stakeholders. Agencies of government, non-governmental organizations, as well as individuals can represent those who will obtain benefits from alleviating problems and realizing opportunities, or who will bear the financial costs or other adverse consequences of any alternative plan. In addition, there may be organizations that are created specifically to include diverse stakeholder interests (e.g., Missouri River Recovery Implementation Committee).

(2) Options for engagement.[15] The following terms describe different levels and forms of agency and stakeholder engagement, including but not limited to engagement with the non-federal project sponsor. Whatever the level and form of engagement, some commitment to effective communication enhances the chance that the preferred alternative (plan) will earn support from those most directly affected by a recommended plan. Many formats for agency and stakeholder communication exist and these can be tailored for each of these levels and forms of engagement.[16]

a) Inform. Communication generally is from the Corps to stakeholders in open public meetings, and the burden is often on the stakeholders to attend the meetings, review information, and provide comments. It is helpful to ask stakeholders during scoping what they perceive to be problems, opportunities, and possible alternatives, and how they wish to be informed as planning proceeds. At each point in the planning process there should be information provided on the progress of the planning process, including what problems and opportunities are the focus and what alternatives are being formulated and evaluated.

b) Consult. The Corps project manager identifies particular organizations, agencies and individuals who are to be consulted with throughout the planning process, seeking their input, considering their concerns and suggestions, and reporting back on what advice was taken, what was not, and why. Engagement of this level and form will almost always be the minimum necessary with the non-federal project sponsors. Whether consultation of this form should be extended to others will be based on a situation assessment [see (3) below].

c) Involve. The Corps project manager identifies particular organizations, agencies, and individuals who will be engaged in a dialogue dedicated to reaching agreement to the extent possible on any matter related to planning, but without an explicit commitment to make reaching agreement a condition for moving forward in the planning process. Engagement of this level and form generally is expected by the non-federal project sponsor.

d) Collaborate. The Corps project manager will identify particular organizations, agencies, and individuals who will participate on the planning team in a shared planning process, with a commitment to seek mutual agreement on analyses related to any step in the planning process. At this level of collaboration, the Corps project manager should consider adoption and implementation of a “Shared Vision Planning” (SVP) or similar process as a possible format for collaborative analysis and planning.

e) Shared decision-making. The Corps project manager identifies those organizations, agencies, and individuals who will have recognized authority or ability to affect the choice of a recommended alternative and/or to implement measures that are part of that alternative. With shared decision-making, the expectation is that there will be a requirement for agreement on all elements of the planning process before a preferred alternative can be recommended and implemented. At this level of engagement, the use of a SVP process, or elements therein, should be fully considered and employed as study resources permit.

(3) Choosing among engagement options. No single engagement approach is appropriate for all situations or for all relevant stakeholders and agencies. In addition, the options for engagement are subject to situation-specific state and federal laws regarding such matters as “government in the sunshine” and the structure of advisory committees. Also, the form and level of engagement may vary at different stages of the planning process. During scoping, the Corps project manager should inventory possible agencies and stakeholders and consult with them about the level, form, and timing of their engagement. In particularly controversial situations, it may be useful to ask an independent and impartial professional to conduct the assessment. This situation assessment then provides the basis for the choice of how to engage with each possible agency or stakeholder group.

a) Situation assessment. A situation assessment may be informal or formal, depending on the scale of the project. The larger or more controversial the project, the more benefit there is in preparing a written assessment document as a basis for gaining a shared understanding of the rationales and expectations for the engagement approach taken with each agency or stakeholder group. Assessments can include initial individual conversations, public meetings, and/or other tools to fully understand and identify the parties that may be affected, the problems and opportunities that are most relevant to these parties, their degree of interest in participating (see levels and forms discussion above), and to identify opportunities for and obstacles to their participation, including time and resource constraints. Information associated with the choice factors below also should be obtained. Educating stakeholders about options for engagement can help them to make an informed decision about how they wish to participate.

b) Choice factors. Factors to consider when making choices on the level and form of agency and stakeholder engagement for each planning element include: the public significance of the project, amount of investment, scientific or technical complexity of the issues and/or degree of uncertainty, degree of controversy and/or relationships among parties (including numbers of parties, cultural diversity, balance or imbalance of power, types of expertise, and resources), time available for consultation within project deadlines, agency staff and budget resources to engage in collaboration, and the preferences of cost share partners and other agencies and stakeholders.[17]

c) Agreement on engagement. A situation assessment will lead to agreement with agencies and stakeholders on the following.

   i. The objectives for engagement, what products are anticipated, and how outputs will be used and by whom in the final decision?

   ii. Who will participate and in what roles (e.g., as representatives of an interest group, as individuals, as experts, etc).

   iii. What processes would be effective and preferred by those participating and what specific procedures and ground rules for engagement will be utilized.

   iv. How analytical results will be reviewed and used in the planning elements and what mechanisms will be used for determining the credibility and usefulness of analyses.

   v. Timing and locations of engagement, under whose auspices meetings are held, and other logistics of involvement.

Section 4. Analytical Elements of Planning [18]

4.1 Specification of Problems and Opportunities

a. Basis. Initially, statements of problems and opportunities will reflect the specific instructions in the study authority, in other instructions by the Congress or the Executive Branch, and with consideration of the expectations of the non-federal project sponsor. The problems to be alleviated and opportunities to be realized should be specified for the planning area as defined in the scoping process. In the process of describing problems and opportunities, the planning area may be adjusted to accommodate new understandings of physical, biological, and economic relationships.

b. Focus and scope. Corps planning will be directed to addressing problems and opportunities (i.e., planning objectives) consistent with Corps statutory authorities and priority missions.

(1) Corps authorities and priority missions include the following general categories of planning objectives:

a) Protect and restore the life support services of nationally significant ecological resources, in cooperation with other federal and non-federal programs and activities, through the management of watershed hydrology and/or geomorphology.

b) Enhance flood and coastal storm damage reduction and risk management, in cooperation with other federal and non-federal programs and activities.

c) Increase the efficiency and reliability of the national transportation system through investment in and operation and management of inland waterways and harbors.

(2) Additional problems and opportunities can be considered in implementation studies if directed by the study authorization, or if they serve agency and stakeholder concerns as long as these problems and opportunities do not conflict with the purposes of the study authority. Possible examples include: a) contribute to reliable water supply for municipal, industrial, and agricultural uses, and b) contribute to renewable energy supply by the production of hydro-electric power. In some cases, stakeholder-defined problems and opportunities may be outside the federal interest (e.g., waterfront renewal), but measures to address the stakeholders' desires can synergistically be made part of the plan, and the costs properly allocated to those purposes.

c. Level of problem alleviation and opportunities attainment. There is no presumption that any specific level of problem alleviation or opportunity attainment must be met. The statements of problems and opportunities describe a desired direction of change from the current and expected future without-project conditions, but do not prejudge how much, if any, of that change may be warranted. [19] Whether and to what level change is secured by some plan is determined by an evaluation of plan monetary and non-monetary benefits in relation to plan monetary and non-monetary costs.

d. Descriptions of problems and opportunities. In specifying problems and opportunities, the following apply:

(1) The problems and opportunities should be described as desired outcomes (e.g., reduce and then manage residual flood risk in River City), and not as an alternative plan(s) that might be presumed to secure those outcomes (e.g., build a levee in River City, or remove structures from the floodplain in River City).

(2) The statement of problems and opportunities should specify metrics for measuring changes in the level and direction of change.

(3) The problems and opportunities should be described for current conditions as well as future conditions that are expected to prevail in the absence of civil works intervention (i.e., the without-project condition).

e. Modifications. Initial expressions of problems and opportunities may be modified during the iterative planning process.

4.2 Inventory Current and Forecast Future Without-Project Water & Related Land Resources Conditions

a. Without-project condition. The forecast of the future level of problems and opportunities that would be expected in the absence of civil works action is the baseline for analysis of the effects of formulated alternative plans on alleviating problems and realizing opportunities. For example, if the problem is reducing and then managing residual flood risk in River City, then the current flood risk as well as the future flood risk, in consideration of socioeconomic change, hydrologic alteration, public policy and other factors, must be taken into account in predictions of future flood risk.

b. Forecast uncertainty. Planners must determine how uncertainty in the future, without-project condition will be addressed in the forecasting of future resource conditions. The uncertainties may be in the water and related land environment (e.g., non-stationarity of the hydrograph, land subsidence), in human activity (e.g., land settlement and population growth) or in limited understanding of hydrologic, geomorphic, or ecological processes (e.g., the fate and transport of sediments, or the response of a wildlife species to changes in the structure and functions of the water and related land ecosystem). Section 3.2.1 (scoping) and Figure 3-1 outlined different approaches for determining when and how to address uncertainty in planning.

4.3 Formulation of Alternative Plans

Alternative plans (or plans) are to be formulated in a systematic manner to ensure that a full set of plans are developed that can reasonably be expected to alter the without-project level of the specified problems and opportunities. Formulated plans need not be limited to include only measures that the Corps could implement directly under existing authorities, and can include measures that can be implemented under the authorities and missions of other federal and non-federal agencies. The scoping process will have established the collaborative relationships to make such cooperation possible in plan formulation. The following considerations will apply to plan formulation.

4.3.1 General Considerations in Plan Formulation

a. Formulation criteria. All alternative plans will be formulated in consideration of three criteria: completeness, effectiveness, and acceptability. [20] In assessing the extent to which a plan meets the criteria, the uncertainty of achieving each criterion should be recognized and reported.

(1) Completeness. Completeness is the extent to which an alternative plan includes all necessary investments or other actions required to ensure the realization of the predicted effects on problem alleviation or achievement of opportunities. This may require relating the actions in the plan to other public or private actions if these other actions are required for alleviating problems or realizing opportunities. Formulated plans should include and report on actions that will be implemented under the authorities of other federal agencies, state and local entities, as well as possible contributions by non-governmental organizations.

(2) Effectiveness. Effectiveness is the extent to which an alternative plan alleviates the specified problems and achieves the specified opportunities.

(3) Acceptability. Acceptability is the extent to which an alternative plan is in compliance with applicable laws and associated regulations, including but not limited to federal and state laws and regulations relating to endangered and threatened species, water quality, cultural and historic resources, and compensatory environmental mitigation under Section 906(d) of the Water Resources Development Act of 1986 as amended (33 U.S.C. 2283(d)). [21] Acceptability also depends on the workability and viability of the alternative plan from the perspectives of relevant state and local entities and the affected public. When institutional barriers related to acceptability would prevent attainment of these criteria, or if compliance with the criteria limits the ability to alleviate a problem or realize an opportunity, plans may be formulated to include recommendations for changes that involve removal of those barriers.

b. Management measures. Plans will be formulated using management measures that in combination address the planning problems and opportunities. “Structural” management measures are defined as those that intentionally modify existing hydrologic and geomorphic structure and processes. Structural measures typically involve implementing, altering, or removing engineered structures. For example, building a new levee and increasing the height of an existing levee are examples of structural measures, as is removal of a levee to allow for hydrologic reconnection of a river to its historic floodplain. “Nonstructural” measures are defined as management measures that avoid and minimize changes to the existing hydrologic and geomorphic structure and processes of water and related land resources. Nonstructural measures include enhanced management of the use of existing infrastructure (e.g., congestion pricing on the inland navigation system) and measures that manage human activity and development (e.g., permanent removal of buildings located in the floodplain). Nonstructural measures can include modifications in public policy, management practice, regulatory policy, and pricing policy.

c. Conceptual compensatory environmental mitigation measures. For each alternative plan expected to have adverse effects on watershed-scale hydrology and geomorphology as well as significant ecological resources at the sub-watershed scale, conceptual compensatory mitigation measures will be formulated. These conceptual measures will be refined once the NEQ effects of plans are fully evaluated. This form of compensatory environmental mitigation is required by law and often may be essential to securing agreement on a preferred plan in a collaborative planning environment.

d. Conceptual compensatory economic mitigation measures. Conceptual compensatory economic compensatory mitigation measures may also be formulated for adverse plan effects on current watershed uses (e.g., current recreation uses), as deemed necessary and appropriate. These may take the form of financial payments or additional measures in the plan (e.g., a new location for a boat ramp, or assured access to an alternative water supply). This form of compensatory mitigation may or may not be required by law (e.g., possible legal requirement to maintain existing benefits of authorized purposes), but even when not, is often essential to securing agreement on a plan in a collaborative planning environment.

4.3.2 Full Array of Formulated Plans

a. Multiple plans. A number of alternative plans should be formulated early in the planning process and then a subset of those plans should be further refined and carried forward for evaluation. Multiple plans should be formulated that reflect possible tradeoffs among the problems and opportunities to be addressed, in recognition of the federal interest evaluation criteria and other relevant state and local considerations.

b. Required plans. The array of formulated plans should include the following required plans that will be carried through to plan evaluation and then to plan display, comparison, and recommendation.

(1) Protection and restoration plan. Except in the case of planning where ecosystem restoration is the only specified problem and opportunity, one alternative plan will be formulated that addresses the specified problems and opportunities by relying principally on management measures that protect (avoid and minimize adverse effects on) or restore watershed scale hydrology and geomorphology, when possible, in support of significant area-specific biological resources. This plan will be identified as the Protection and Restoration Plan and will be carried through the balance of the planning process and used as outlined below.[22]

There are two reasons to require formulation of a Protection and Restoration Plan. One is to assure that at least one plan that makes a contribution to alleviating problems and realizing opportunities while avoiding adverse impacts on watershed hydrology and geomorphology, and restoring these same features if possible, is fully developed and carried forward to evaluation, comparison, and consideration for recommendation as the preferred plan. It is recognized that in some planning contexts such a plan may not meet all of the formulation criteria outlined in Section 4.3.1 (completeness, effectiveness, acceptability), and thus may not have realistic prospects for recommendation as the preferred plan. However, even when the Protection and Restoration Plan is unlikely to be identified as the preferred plan, it will be used as a point of reference when displaying the tradeoffs among it and all other plans that have been formulated to address problems and opportunities in plan comparison. The use of the Protection and Restoration Plan for this purpose is outlined in Section 4.5.[23]

(2) Adaptive management plan. If deemed advisable and practical after consideration of the consequences of uncertainty on path 3 [see Section 3.2.1d.(2) and Figure 3-1], at least one formulated plan will include adaptive implementation elements designed to reduce knowledge uncertainties attributable to analytical limitations in order to increase confidence that the

intended outcomes of the plan will be realized over time. If the formulation process does not identify a viable adaptive management plan, the study will document efforts to identify such an alternative and explain why it could not be formulated. [24]

4.4 Evaluation of Alternative Plans

Each formulated plan will be evaluated for its contribution to national economic efficiency (NEE) and national environmental quality (NEQ), as measured against the without-project condition. Plans will also be evaluated for their effects on the additional federal interest evaluation criteria as deemed necessary for informed decision-making in a particular planning context, including public safety effects, other environmental quality effects, and other social effects.

4.4.1 Prediction of Plan Effects

Predictions of the effects of alternative plans made using metrics for representing the level of problem alleviation and opportunities attainment, as measured against the without-project condition, should be made for selected years over the period of analysis. The predictions made should draw upon official or otherwise recognized and accepted sources for matters such as, but not limited to, national and regional projections of income, employment, output, and prices for specific goods, services and commodities, population, exports, and environmental conditions. Depending on the treatment of uncertainty chosen during scoping, uncertainty in predictions should be characterized quantitatively or qualitatively, and the effects on evaluation metrics for the evaluation criteria described.

4.4.2 Primary Evaluation Metrics

NEE and NEQ measures will be the primary measures reported to facilitate evaluation and comparison of alternative formulated plans for alleviating problems and realizing opportunities.

a. National Economic Efficiency (NEE) metrics. NEE effects will be measured as the positive and negative effects of plans on the economic value of water and related lands, or the economic value of the national output of goods and services produced using these resources, as expressed in monetary units. [25]

Economic benefits will be measured as increases in monetary units reflecting beneficiaries' willingness to pay (WTP) for increases in the economic productivity of affected water and related land resources, or increases in the national output of goods and services produced using these resources. Economic costs will be measured in monetary units reflecting plan implementation and associated costs, as well as the opportunity costs to affected individuals resulting from any decrease in economic productivity of water and related land resources, or decrease in the national output of goods and services produced using those resources.

b. National Environmental Quality (NEQ) metrics. NEQ effects of plans will be measured as the positive and negative changes in the physical, chemical and biological conditions of the nation's significant water and related land resources at the watershed scale, as expressed in non-monetary units.

The NEQ effects of alternative plans will be evaluated using metrics that are biologically-meaningful. The chosen metrics may include readily measured and predicted changes in hydrologic and geomorphic structure and processes in rivers and coastal systems. Examples include area of floodplain reconnected to a river (surrogate for enhanced native fish spawning and refuge as well as nutrient trapping), increases in area of emergent sand bars (surrogate for bird population increases) or changes in the shape of the hydrograph (surrogate for fish productivity, riparian habitat creation, and invasive species control). Alternatively, metrics might be developed and used that are more directly related to the desired biological outcomes, such as changes in habitat suitability indices for one or a community of species. In all cases the effect of an action on the chosen metric should be predictable with an acceptable degree of uncertainty, as judged by decision participants.

The direction of NEQ effects can be either positive of negative. In order to determine the direction of change when the biological outcome is not measured directly, it may necessary to describe a reference condition. Consider a metric where life support for a specific fish species is the biological outcome and the shape of the hydrograph best suited to fish spawning is the metric. In this case the past hydrograph or the hydrograph on a river with a viable fish population might be the reference condition.

Negative NEQ effects may occur in two ways and the response in plan formulation is different. First movement away from the desired biological outcome or reference condition, under the future without-project condition, is a negative change in NEQ that has no relation to the proposed action (plan), but is the basis for measuring positive NEQ effects when plans are formulated to add to NEQ. This is termed "restoration." [26]

Second, a negative NEQ effect may occur as the result of a proposed action (plan), when measured against current resource conditions and not the reference condition. Supplemental plan features or changes made to a plan with the purpose to maintain NEQ or minimize the negative NEQ effects of plans in relation to the current resource conditions are not restoration, but rather are termed compensatory environmental mitigation. The same metrics may be used to measure both restoration benefits and to establish a level of compensatory environmental mitigation.[27]

4.4.3 Additional Evaluation Metrics

Plan effects on public safety, other environmental quality effects, and other social effects may be measured and reported, as required to satisfy the information requirements of all parties engaged in decision-making, or to meet other reporting expectations.

a. Public safety (PS) metrics. PS effects of alternative plans will be measured as the changes in risks to human life and safety from flood and coastal storm hazards, and other potential hazards as warranted, and risks that remain after plan implementation (residual risks), as expressed in various quantitative units or qualitative descriptions. An accounting of residual risks to human life and safety is required when flood and coastal storm threats are identified as problems and opportunities to be addressed in a planning study. PS effects will be measured in non-monetary units or qualitative descriptions relating to one or more of the following determinants of flood and coastal storm risk:

(1) Hazard (e.g., frequency and intensity of possible floods and storms that exceed the design level of any hazard reduction measures included in plans).

(2) Exposure (e.g., the number of people potentially exposed to residual flood and storm hazards).

(3) Vulnerability (e.g., the ability and means of potentially exposed populations to evacuate or otherwise avoid or mitigate injury and death from residual flood and storm hazards).

b. Other environmental quality (OEQ) effects metrics. OEQ effects will be measured as the effects of alternative plans on significant cultural, aesthetic, and sub-watershed-scale ecological resources, as measured using appropriate non-monetary indicators. An appropriate indicator is a characteristic of a relevant resource that serves as a direct or indirect means of measuring or otherwise describing changes in the quantity and/or quality of resource attributes.

c. Other Social Effects (OSE) Metrics. OSE will be measured as the effects of alternative plans on low-income, tribal, and minority communities, [28] as expressed in monetary units, non-monetary units, or qualitative descriptions relating to one or more of the following:

   (1) Changes in employment, wages, and other measures of economic activity within the community.

   (2) Incidence of NEE and NEQ effects on groups within the community.

   (3) Incidence of PS and OEQ effects on groups within the community.

4.4.4 General Considerations in Plan Evaluation

a. Measurement of national economic efficiency effects. Measurement of economic benefits and opportunity costs (foregone benefits) in monetary units will generally be made for affected goods and services that are marketed, as well as those that are not marketed but that have a substitute good or service that is marketed.[29] However, any plan effect may be assessed in monetary units if the following conditions hold: (1) the assessment can be accomplished using the available study resources in consideration of all study requirements; (2) the assessment is deemed by the District Engineer to be important for informed decision-making, and; (3) the assessment is broadly viewed as valid and acceptable by the project stakeholders that are engaged in decision-making.

b. Accounting for an effect in multiple ways. Any plan effect can be measured and shown in different ways across multiple effects categories to allow decision-makers to consider that effect from alternative perspectives. As one example, the flood damage reduction effects of plans can be measured and shown as monetary NEE metrics (property damages avoided), as hydrologic PS metrics (the level of residual hazard), and as OSE metrics reflecting the incidence of these measured effects on low-income, tribal, and minority communities.

c. Compensatory environmental mitigation costs. For each alternative plan that has adverse watershed-level and/or sub-watershed-level effects on significant ecological resources as measured by NEQ and OEQ metrics, respectively, conceptual compensatory environmental mitigation measures will be developed and the costs of these measures will be assessed and recorded as part of the NEE evaluation.

d. Compensatory economic mitigation costs. As deemed necessary and appropriate, conceptual compensatory economic mitigation measures may be developed for adverse plan impacts on current watershed uses (e.g., current recreational uses) and the costs of these measures (e.g., replacement of recreational access, payments to purchase water rights or replacement power supply, relocation assistance payments) assessed and recorded as part of the NEE evaluation.

e. Life cycle analysis.

(1) Period of Analysis. The period of analysis is to be the same for each alternative plan. The period of analysis is to be the time over which any alternative plan would have significant beneficial or adverse effects on the federal interest evaluation criteria.

(2) Time pattern of effects. Positive and negative NEE and NEQ effects may not occur uniformly over the period of analysis.

a) Some alternatives that rely on hydrologic and geomorphic restoration through the mimicking of natural processes may cause NEQ improvements to come about slowly, but then become self-maintaining (i.e., not require occasional interventions) and self-designing at some point in time. That time pattern of effects should be recognized and reported.

b) Future NEE benefits may not occur in the same year for all plans and some plans may have different levels and frequency of costs. For all plans, the years that different levels of benefits are realized and the years that different levels of costs are incurred for operations and maintenance and for significant repair and replacement should be reported.

(3) Discounting. Discounting will be used to convert all future NEE (monetary) effects to present values using the discount rate established annually for civil works planning. Discounting may be applied to NEQ effects, for present value comparison with NEE effects, as long as the time patterns of NEQ benefits and costs to realize those benefits over the project life are also reported. [30] Non-monetary effects with respect to the other evaluation criteria (PS, OEQ and OSE effects) would not normally be discounted for plan display and evaluation.

f. Prices of goods, services, and factors of production. The prices of goods, services, and factors of production (i.e., input costs) should reflect real exchange values expected to prevail over the period of analysis. To the extent practical, direct government subsidies or other programs that affect observed exchange values should be recognized and adjustments made to those prices to reflect real exchange values. If adjustments cannot be made, the subsidies that distort real exchange values should be identified and described. [31]

4.5 Plan Display and Comparison

a. General considerations in plan display and comparison.

(1) To assure transparency and full recognition by decision participants of the different plan effects and the different parties that may realize them, all predicted effects for each plan, even if expressed in commensurate metrics (e.g., monetary units) should be left disaggregated (i.e., not summed or otherwise combined) for the purpose of plan display and comparison. For example, estimated monetary benefits from addressing a specific problem or opportunity (e.g., flood risk management) should be shown separately from the estimated financial costs of plan implementation, as well as separately from the estimated monetary value of any incidental plan benefits or foregone benefits associated with other affected goods and services (e.g., recreation). For purposes of recommending a plan, however, aggregation may be applied, as outlined in Section 4.6.

(2) The one exception to the requirement for disaggregation of plan effects involves a measure of total financial costs for plan implementation, which can be shown as the total discounted present value sum of all financial component costs for implementing a plan (e.g., initial capital costs, annual O&M costs, costs associated with future repair or other necessary interventions). Even in this case, however, each individual component of plan financial costs should be shown separately along with the sum and time pattern of plan financial costs for plan display and comparison.

(3) To assure transparency in the characterization of conceptual environmental and economic compensatory mitigation proposals, the adverse effects, a description of the conceptual compensation plan, and preliminary estimates of the financial costs of implementing the compensation for each formulated plan should be shown separately in the plan display and comparison. [32]

b. Phase 1 plan display and comparison. There are two phases in plan display and comparison. Phase 1 will display and compare the evaluated effects of plans using the primary evaluation criteria (NEE and NEQ). The set of plans included in Phase 1 display will include the Protection and Restoration Plan as well as all evaluated plans that meet the formulation criteria outlined in Section 4.3.1. The purpose of the Phase 1 display and comparison is to narrow the set of plans that will be carried forward for Phase 2 plan display and comparison (another purpose is to identify plans that might be improved by reformulation and then considered further through the iterative process).

(1) A Phase 1 display will be developed to report the effects of plans in terms of each evaluated NEE and NEQ effect as well as any conceptual compensatory mitigation plans and associated costs. Specifically, the following effects should be included and shown separately in the display matrix:

- NEE monetary benefits for each good or service for which plans have been formulated to produce (i.e., evaluated economic benefits for addressing specified problems and opportunities).
- NEQ non-monetary effects, both positive and negative, as measured using one or more NEQ metrics.
- NEE monetary benefits and costs associated with other affected goods and services. These effects can include incidental benefits for each positively affected good or service, as well as the opportunity costs (benefits foregone) for each negatively affected good or service.

- NEE financial costs for plan implementation, including the following component and total costs shown separately: a) initial capital outlays, b) annual operation and maintenance costs, c) costs for future repair and any other necessary interventions, and d) total financial costs for plan implementation (discounted present value sum of cost items a-c).
- A description of the conceptual compensatory environmental mitigation proposal for adverse NEQ effects and adverse OEQ effects, and the financial costs of implementing the proposal.
- A description of the conceptual economic compensatory mitigation proposal for adverse effects on existing watershed uses, and the financial costs of implementing the proposal.

(2) The display should refer to the places in the report where the analysis supporting the results reported in the display can be found.

(3) The Phase 1 display will be used to compare the effects of alternative plans in order to judge whether some plans are "inferior" to one or more other plans. NEE benefits and costs for incidental goods and services, as well as conceptual compensatory mitigation plans and associated costs, can be used as supplemental information for judging whether certain plans are inferior to one or more other plans. Any of various methods and associated graphical displays and plots for multi-criteria comparisons of plan effects may be employed to facilitate plan comparison. The result of the comparison should be a narrowing of the set of plans to be carried forward for the Phase 2 plan display and comparison. (Another possible result is a decision to reformulate and reevaluate one or more plans that have been judged to be inferior).

c. Phase 2 plan display and comparison. Phase 2 will focus on the display and comparison of the evaluated effects of non-dominated plans relating to all evaluation criteria, both primary and additional. The set of plans included in this phase will include the Protection and Restoration Plan as well as the subset of plans that have been carried forward from the Phase 1 plan display and comparison. The purpose of this second round of display and comparison is to identify a subset of plans that will be considered for possible recommendation as the preferred plan.

(1) The Phase 2 display will be developed to report the effects of plans that have been carried forward in terms of all evaluation criteria, including the primary criteria (NEE and NEQ), the additional criteria (PS, OEQ and OSE), as well as conceptual compensatory mitigation plans and associated costs. As in the Phase 1 display, each evaluated effect should be displayed separately.

(2) The Phase 2 display will be used to identify plans that may be considered unacceptable based on their effects on the additional evaluation criteria (e.g., unacceptable public safety effects), and should be screened from further consideration (or reformulated).

(3) The Phase 2 display will be used to identify and consider the incremental NEE and NEQ effects of plans as measured against those of the Protection and Restoration Plan. Any of various types of methods for implementing incremental analysis may be employed for illustrating the incremental NEE and NEQ gains and losses from moving from the Protection and Restoration Plan to each of the other plans. The result of this incremental analysis should be the selection of a subset of plans to be considered for possible recommendation as the preferred plan. [33]

(4) If the Protection and Restoration Plan meets the formulation criteria set out in Section 4.3.1, it should be included in the set of plans carried forward for possible recommendation.[34]

4.6 Plan recommendation

a. The responsibility of the planning process is to provide useable information for those with decision-making authority. The responsibility of those with decision-making authority is to use the information provided to conclude whether one or more alternative plans for a specific place are in the federal interest and can be considered for selection, and then recommend one of those plans as the preferred alternative.

b. Decision-making responsibility [35]

(1) Within the Corps, the District Engineer (DE) has the initial responsibility for making a federal interest determination and recommending a preferred plan. While the Corps decision begins with the DE, the recommendation for a preferred plan is ultimately the responsibility of the Corps organization and the Assistant Secretary of the Army for Civil Works [ASA (CW)]. Because of the in-progress review process of the Corps, the DE recommendation should be that of the agency as a whole.

(2) Project cost share partners make a financial commitment to developing the plan and will have financial obligations for plan implementation. The DE will share the display and comparison information and engage with cost share partners in selecting a preferred plan.

(3) Other federal agencies and non-federal government agencies may have projects and programs that are part of any formulated plan in the final array of plans, or may have responsibility to approve any plan before it may be implemented. The DE will be expected to share the display and comparison information and engage with other agencies of government in selecting a preferred plan.

(4) The Executive Branch, through the Office of Management and Budget and the Council on Environmental Quality, as well as the Congress has responsibility for reviewing the Corps recommendation, and through the legislative process, making the final determination on authorization and appropriations. Therefore, the Corps may, through the Office of the ASA (CW), share the display and comparison information and engage these entities before recommending a preferred plan.

c. Plan recommendation and reporting responsibilities

(1) The DE will provide a summary of all technical review comments from the technical review processes in place and a response to the comments indicating how they were addressed, and if rejected, the basis for that rejection. These will be part of the information made available for agency and public comment.

(2) The DE will publish the display and comparison information for all plans for a concurrent 90 day public and agency comment period, and will provide a summary of public comments as well as a response to the comments indicating how they were addressed.

(3) The DE will prepare a written statement indicating the basis for the following determinations (specifically referring to the results in the Phase 1 and Phase 2 display and comparison, to the technical review comments, to public and other agency comments, and to the preferences of the cost share partners):

- Which plans displayed in Phase 1 were not carried into Phase 2.
- Which plans in Phase 2 did not meet a federal interest determination and were not further considered for the preferred plan.
- If the Protection and Restoration Plan is not recommended, the reasons for that decision.
- The reasons for selection of the preferred plan.
- If the DE determines that no plan is in the federal interest, then a no federal action alternative will be recommended as the preferred plan.

In preparing the written statement in support of the preferred plan, the DE may choose to aggregate the effects that were disaggregated in the plan display and comparison phases in ways that the DE believes can help clarify the basis for the decision made. The choice to aggregate the measures of NEE, NEQ, and other effects, and how that aggregation is executed, is at the DE's discretion. [36]

(4) The DE will ask the cost share partners and other agencies who have agreed to implement elements of the preferred plan to prepare a statement to accompany the DE recommendation supporting the recommendation and providing evidence for their commitment and capacity to implement their elements within the plan. The partners will comment on the logic used by the DE and may provide additional reasons for supporting the recommendation.

Appendix A: Formulation and Evaluation of Alternatives Affecting Floodplains, Flood Risk Management, and Public Safety

Background

Current Corps guidance says that planning studies for flood and coastal storm damage reduction (F&CSDR) projects should generally recommend project plans that maximize net national economic benefits subject to an environmental protection constraint. Benefits are measured as expected property damages avoided by a plan, and the analysis of plans is to report an estimate of the residual expected annual property damages that would occur with the alternative in place. Planning guidance does not require that benefits from reduced risks to human life and safety as well as the residual risks to life and safety with the plan in place be quantified and discussed in F&CSDR studies (though in recent years the Corps has increased attention to residual risks to human life and safety in planning studies).

Current Corps policy does not specify any minimum level of project performance that must be provided, but net economic benefits must be positive for whatever plan is recommended. However, a non-federal sponsor may desire a plan that provides a different level of performance than that provided by the plan that maximizes net economic benefits. This might be a desire to have no properties exposed to the 1% annual chance flood event that affects community requirements under the National Flood Insurance Program. If a non-federal sponsor prefers a plan that eliminates exposure to the 1% annual chance flood event (but not to floods of higher magnitudes and lower likelihoods of occurrence), and that plan has net economic benefits, Corps policy allows it to be recommended without formulating and considering other plans. Alternatively, a non-federal sponsor might prefer a plan that eliminates exposure to higher magnitude and less frequent flood events (i.e. that provides a higher level of performance) than that associated with the plan that maximizes net economic benefits, and be willing to adjust the cost share to secure that plan.

Corps policy also directs planners to formulate and consider a primarily “nonstructural” (NS) plan in F&CSDR studies, which has been generally understood to incorporate measures designed to reduce determinants of flood risk other than the flood hazard (that is, these risk reduction measures do not focus on reducing flood surface water elevations in the floodplain). The use of such management measures is promoted by environmental advocacy groups and others as a means to achieve flood damage reduction while avoiding and minimizing changes to existing watershed hydrology and geomorphology, thus limiting negative impacts on the “natural and beneficial functions” of floodplains and wetlands.

NS measures for flood damage reduction include the removal/relocation (buyouts) of structures in the floodplain that can reduce the potential for people and assets to come into direct contact with floodwaters by changing use of the floodplain (that is, measures that reduce “exposure”). They also include measures such as flood warning and preparedness systems and flood-proofing of buildings that can reduce the negative consequences that occur when people and assets are exposed to flood hazard by accommodating existing floodplain uses to that hazard (that is, measures that reduce “vulnerability”). Measures to reduce exposure and vulnerability are typically considered together in the formulation of the NS plan, but usually with limited or no measures to reduce flood hazard. The NS plan is often found by the Corps to fail the net economic benefits test and/or is deemed unacceptable by non-federal project sponsors, however.

Nevertheless, some management measures to reduce exposure or vulnerability are usually included in F&CSDR plans that are recommended for implementation. For example, limited buyouts are sometimes used to reduce the costs for levee alignments, or to contribute to community amenities such as river access that are often important for local acceptability of project plans. Further, project partnership agreements require non-federal sponsors to implement floodplain management plans and comply with NFIP requirements. Moreover, in recent years Corps policy and guidance have allowed for the formulation of "combined" plans that can jointly protect and restore floodplain and upstream wetlands while also reducing flood risk. This has allowed planning to formulate and consider plans that include what might be termed "natural infrastructure hazard reduction" measures, such as levee setbacks for local floodplain restoration and upstream watershed restoration.

In addition to having positive net economic benefits, a recommended plan must be consistent with "protection of the Nation's environment." In practice, that environmental protection constraint is deemed satisfied by making compensatory environmental mitigation measures part of the plan, and factoring the mitigation costs in the net benefits calculation for the plan. Corps guidance expects that the environmental quality effects of any plan to be evaluated in non-monetary terms and used to determine any necessary environmental mitigation for that plan. But there is no expectation that Corps planners should consider and balance tradeoffs among the evaluated environmental quality effects and economic effects of plans in plan comparison and selection.

Motivations for Change

Critics of the Corps planning processes for F&CSDR note several areas of concern. Among the criticisms is that past Corps F&CSDR studies have:

1. Focused too much on formulating plans that rely on "hard" hazard reduction measures such as upstream reservoirs, levees, and channel modifications to the exclusion of plans that include natural infrastructure hazard reduction measures (as defined above) in combination with measures that can reduce community exposure and vulnerability to flooding.

2. Failed to measure and use information on the negative and positive effects of plans on floodplain and wetlands functions in plan formulation, evaluation, comparison, and selection.

3. Failed to measure and use information on plan effects for reducing risks to human life and safety, as well as the residual risks to human life and safety that would remain following plan implementation, in plan formulation, evaluation, comparison, and selection.

Options for Modernizing Corps Guidance

The desire that combinations of natural infrastructure and exposure and vulnerability reduction measures be given more serious attention and consideration in F&CSDR studies could be addressed by requiring one plan to be formulated by starting with and then adding successive increments of such management measures. The intent of this plan would be to address problems and opportunities while also avoiding and minimizing adverse impacts on (and restoring, when possible) floodplains and related wetlands functions; the framework presented here calls such a plan the "Protection and Restoration Plan."

The effect of requiring formulation of a Protection and Restoration Plan would be to address one of the criticisms of current practice. The requirement would assure that at least one plan that makes a contribution to flood damage reduction while avoiding and minimizing adverse impacts on watershed hydrology and geomorphology (and restoring these same features, when possible) is fully developed and carried forward to evaluation, comparison, and consideration for recommendation as the preferred plan. It is recognized that in some planning contexts the Protection and Restoration Plan might involve unacceptably high residual flood risks, and thus may not have realistic prospects for recommendation as the preferred plan. Other plans could be formulated that build on the Protection and Restoration Plan by adding traditional hazard reduction measures (e.g., levees and channel modifications) as next added increments to the plan. In addition, plans that have hard infrastructure as the first increment, and add natural infrastructure and nonstructural measures as next added increments, might also be developed.

The Protection and Restoration Plan would also make a contribution to plan evaluation and to informing selection of a preferred plan by serving as a point of reference when comparing the NEE, NEQ, and other effects of other plans. That is, the Protection and Restoration Plan would serve as a point of reference when displaying the tradeoffs among it and all other plans that have been formulated, evaluated, and carried forward for possible recommendation. The analysis would document the NEE, NEQ, and other (e.g., public safety) effects of the Protection and Restoration Plan for reducing and managing flood risks. The analysis would then systematically report the incremental changes in NEE benefits and costs and NEQ and other effects that would be realized if other plans were selected instead of the Protection and Restoration Plan.

Similarly, the desire that the public safety (PS) effects of alternative plans be considered in planning could be made operational by requiring the evaluation and comparison of plan effects on risks to human life and safety as well as risks that would remain after plan implementation (residual risks). PS effects could be measured in non-monetary units or qualitative descriptions relating to one or more of the following determinants of flood and coastal storm risk: 1) Hazard (e.g., frequency and intensity of possible floods and storms that exceed the design level of any hazard reduction measures included in plans); 2) Exposure (e.g., the number of people potentially exposed to residual flood and storm hazards), and 3) Vulnerability (e.g., the ability and means of potentially exposed populations to evacuate or otherwise avoid or mitigate injury and death from residual flood and storm hazards).

Commentary

In recent years the Corps has begun to reinterpret its F&CSDR missions within the broader concept of flood risk management, which recognizes that responsibility for reducing flood risk and managing residual risk must be shared among the Corps, local governments, and affected citizens. Shared responsibility implies that the localities that the Corps assists through F&CSDR projects are expected to play a role in "buying down" flood risks, and then assume primary responsibility for managing residual risks. As one example, all Corps F&CSDR projects might be expected to incorporate flood warning and preparedness systems, where these project features would be operated and maintained by local authorities. Similarly, while current Corps policy makes federal participation in a project contingent upon local implementation of floodplain management regulations, policy adjustments may be needed to ensure local compliance.

Shared responsibility also implies shared decision-making in which the desires of non-federal project sponsors must be taken into account. Thus, decisions must be made in consideration of the level of residual risk that non-federal sponsors deem acceptable, as well as the tradeoffs that they are willing to make among flood risk reduction using natural infrastructure hazard reduction and measures to reduce exposure and vulnerability, as opposed to traditional hazard reduction alternatives. In the end, shared responsibility for choosing a preferred plan must be accompanied by a shared commitment to implementing all elements of the plan and to continuous monitoring of that implementation over time.

The concerns that motivate criticisms of how floodplains are considered in plan formulation, evaluation, comparison, and selection are already addressed, however imperfectly, in current Corps planning guidance. In fact, there has been increased inclusion of natural infrastructure as well as exposure and vulnerability reduction measures in plans being proposed for authorization. Changes to guidance can be made to require greater consideration of natural infrastructure in plan formulation and evaluation by requiring formulation of a Protection and Restoration Plan and by using that plan as a point of reference for comparing the NEE, NEQ, and other effects of all other formulated plans.

However, considering a Protection and Restoration Plan for recommendation would necessarily depend on the available opportunities for such alternatives and their acceptability to non-federal sponsors. Many non-federal sponsors for Corps studies represent heavily populated areas where opportunities for natural infrastructure hazard reduction as well as exposure and vulnerability reduction may be limited. Therefore, while guidance changes may address the concern that the current practice of F&CSDR study execution does not give balanced consideration to plans that emphasize exposure and vulnerability reduction and natural infrastructure hazard reduction, in the end such changes in guidance cannot ensure that such plans would be deemed acceptable to non-federal sponsors.

Appendix B: Objectives and Evaluation in Civil Works Planning Studies

Background

This Appendix uses the concept of "ecosystem services" to explore issues relating to the evaluation of plan effects in a planning study. While numerous references provide somewhat varying definitions for the ecosystem services concept, most argue that ecosystem services are "natural" services provided by the environment that make a direct or indirect contribution to the well-being of people.

In the next section we re-interpret the meaning and implications of ecosystem services in ways necessary to make the concept operational within the authorities of the Corps and within the context of a watershed as opposed to ecosystem focus for Corps planning. The result is to derive the idea of "watershed services" from the concept of ecosystem services.

That is followed by a review of the Corps' current approach to the evaluation of changes in watershed services for civil works planning. Motivations for change to the current approach are then outlined, followed by a discussion of options for change. Particular attention is paid to the possibilities for, and limitations of, placing monetary values on all watershed services that may be affected by project alternatives.

Watershed Services

The structure and processes of river and coastal watersheds constitute "natural infrastructure" that in turn supports or directly provides natural services that are valued by people. Of course, this natural infrastructure exists alongside human infrastructure, and may have been altered by human interventions and uses over time, often by Corps projects. Below, we refer to this combination of natural and human infrastructure as "watershed structure and processes."

Watershed structure refers to the geophysical features and characteristics of a watershed at a point in time, such as topography and land cover, including the kinds and locations of wetlands, land uses, as well as the existing water control structures that affect the hydrologic and geomorphic regime of rivers, lakes, and related estuaries. Watershed processes refer to geophysical processes such as gravity and solar and wind energy that contribute to the hydrologic cycle and the movement of water and sediments through the geophysical structure, as affected by ecological functions, such as biomass production and nutrient cycling, that are present given some watershed structure.

Examples (not an exhaustive list) of four types of watershed services that are especially relevant to civil works are presented in the box below. The *Millennium Ecosystem Assessment* and other sources provide different, but generally consistent, categorization frameworks. We use this particular framework because it is readily interpreted in terms of the combined effects of natural and human-made infrastructure on the types and levels of watershed services that are most affected by the Corps civil works program.

Examples of Watershed Services Relevant to Civil Works

Input in Production of Marketed Goods & Services

- Waterway transportation
- Flood storage & conveyance
- Hydropower generation
- Water input and land productivity for agriculture and commercial & industrial production

Direct Use

- Municipal & home water supply
- Recreation & aesthetics

Waste Assimilation

- Processor or sink for human waste products
- Trap for eroded soil

Life Support

- Biodiversity
- Populations of one or more wildlife species

Watershed services that are valued as production inputs for marketed goods and services most closely align with the types of services that have been the objective for formulation of alternatives in traditional Corps water development projects. In most cases, those services were expected to be captured or enhanced by the construction of water control works.

The waste assimilation services may be used by intention, but often they are simply the inevitable result of human activity in the watershed. Management of the use of these services is the responsibility of the USEPA and state water quality agencies. However, if Corps projects or their operations affect the flow patterns and geomorphologic processes in rivers, then waste assimilation services may be enhanced or reduced. Other civil works actions have also been associated with waste assimilation service provision; for example, the restoration of wetlands areas may increase sediment trapping.

Most references to ecosystem services characterize life support services (as well as waste assimilation services) as “ecological” services that are most closely associated with natural infrastructure where, in the case of watersheds, “natural” is defined with reference to some pre-disturbance watershed hydrologic and geomorphic structure and processes. That is, it is presumed that life support services were provided at their maximum levels in that pre-disturbance state. These services are valued by people directly as well as indirectly through the support they provide for other services, such as recreation.

At the federal level, management of life support services is the responsibility of resource agencies such as NOAA and USFWS, and is also addressed by the Corps regulatory program under Section 404 of the CWA. With respect to Corps civil works missions and authorities, life support services may be diminished or may be enhanced by interventions in watershed structure and processes. However, the specific effects on life support services that would result from civil works interventions in watershed structure and processes may be difficult to separate from other factors, such as harvest pressure or nutrient levels in a river.

The specific types and levels of watershed services realized in any specific watershed are affected by water development projects and other human-made alterations to watershed structure and processes. Indeed, the intent of human interventions has been to increase the supply of one or more watershed services, since in many cases the service contribution to the well-being of people largely depends on such interventions. For example, rainfall, runoff, and water storage in rivers and lakes make a contribution to the municipal water supply service, but capital investment for the capture, treatment, and distribution of the water is required for this service to add to the well-being of people.

Current Evaluation Practice

Federal budget priorities, Congressional authorization language, interpretations of Corps legal authorities, and preferences of local cost sharing sponsors direct most Corps planning studies to formulate alternatives to enhance production inputs for marketed goods and services. These planning processes focus on waterborne commercial transportation and flood and coastal storm damage reduction, which the current Corps planning guidance refers to as “National Economic Development” (NED) outputs. More generally, these planning processes emphasize reducing the adverse consequences to people from extreme high-water and low-water conditions in the flow of the river at a location (the hydrograph), or that offset those effects by flood hazard reduction infrastructure (to address floods) and temporal and spatial water transfers (to address drought). These engineering works include dams and reservoirs, channel straightening and deepening, pipelines, and levee systems. With respect to coastal harbor development, the approach has been to accommodate deeper ship drafts and wider ships through channel deepening and port widening. In some studies, “nonstructural measures” (actions that do not alter the existing hydrology or geomorphology) are considered when formulating alternatives.

The evaluation of the effects of formulated plans on these kinds of NED outputs is based on the objective of national economic efficiency. The economic efficiency benefits are understood as the willingness to pay (WTP) of project beneficiaries for a change in services and are expressed in monetary terms, typically using WTP proxies. Once estimated, the benefits are compared with estimated costs (financial outlays and opportunity costs) to recommend the plan that maximizes net economic benefits. The WTP benefits may be limited to a specific type of benefit resulting from the change in a service (e.g., flood damage reduction benefits have been monetized primarily with reference to property damages avoided). In addition, other non-monetary evaluation metrics are often reported (e.g., level of protection in a flood damage reduction project).

Corps guidance also expects non-monetary estimation of the environmental quality (EQ) effects of plans formulated to serve NED outputs. The federal objective statement in current Corps guidance directs selection of the plan that maximizes net NED (monetary) benefits, but subject to a constraint that the plan must comply with applicable environmental laws and regulations. As a practical matter, this requirement demands an evaluation of environmental effects and recognition of such effects as they may constrain how plans are formulated, and consideration of such effects for determining any required environmental compensatory mitigation for a selected plan. Estimated costs in the net benefits analysis include expenses for any required compensation.

In recent years, the Corps has had the authority and budget to plan for and implement a category of projects that focus on "National Ecosystems Restoration" (NER) outputs (what the framework presented here labels as NEQ effects) as well as combined NED/NER outputs. In these planning efforts, plans are formulated to enhance life support services (the outputs) through the "restoration" of hydrologic and geomorphic structure and processes of rivers and associated wetlands and floodplains. Specific types of interventions in watershed structure and processes to enhance life support services include replicating historic high and low flows on the hydrograph, creating wetlands and riparian floodplain acres, restoring the original hydro-period of remnant wetlands, and reconnecting rivers to floodplains. This category of planning studies often considers the construction of new engineering works, but may also consider the re-operation, removal, or relocation of existing works. High-profile examples include the Kissimmee River restoration and the Comprehensive Everglades Restoration Plan (CERP) that are being implemented in cooperation with the South Florida Water Management District. (There are numerous examples of other, less well-publicized NER projects that are smaller in scale.)

Formulation of alternative plans for NER usually begins with attention to place-specific, biological goals (life support services). The mix of actions considered and their specific designs are guided by an implied or explicit "conceptual ecological model" that relates the actions that the Corps might take to the life support needs of desired target species or communities of species in the watershed where the plan is being executed. For example, formulation of plans to change reservoir operations for temperature modification might be conceptualized in terms of the needs of a specific cold-water fish species indigenous to that river system. As another example, levee setbacks with the construction of side channel habitats in the land reconnected to the floodplain may allow for improved spawning and nursery opportunities for a particular fish species.

It follows that the evaluation of these plans will use metrics that correspond to the place-specific biological objectives. Measures of NER benefits might focus on changes in existing watershed structure and processes that support place-specific biological objectives. These may include evaluation metrics reflecting acres of reconnected floodplain or the shape of the hydrograph at some point in the spawning season for the relevant fish species. Alternatively, evaluation metrics might be changes in a habitat suitability index (and area) for a target species or an ecological community. Whatever non-monetary evaluation metric is used for evaluation, it is related to the costs for each plan through a cost-effectiveness analysis and incremental cost analysis in order to identify cost-effective alternatives and then a "best buy" alternative. A determination of the "significance" of the affected resources and expected changes in life support services also plays a role justifying a selected NER plan. By Corps policy, the WTP (monetary) metric is not employed for representing NER outputs.

A NER plan may also indirectly increase or decrease any of the other watershed services; however, changes in those other services may not be evaluated in monetary or non-monetary terms, although there is no prohibition against such evaluation. For example, a floodplain reconnection to a river to increase spawning habitat for a particular species may also reduce downstream flood peaks, but any associated flood damage reduction benefits are typically not evaluated and considered in selection of a preferred plan.

Of note here is the concept of "incidental benefits" as defined by Corps policy and planning guidance. For example, plans that are formulated to provide flood damage reduction may also increase the quality of existing recreation services, and Corps guidance encourages the estimation of monetary benefits for such effects when practical. However, depending on the type of service, Corps policy may limit the extent to which such benefits can be included in net economic benefit calculations (in the case of planning for NED outputs) and cost-effectiveness and incremental cost analyses (in the case of planning for NER and combined NED/NER outputs), and thus play a role in plan selection. This limitation is what makes the benefits “incidental.” In certain cases, Corps policy does allow for the use of incidental benefits for justifying a plan. One example involves the permanent removal of structures in the floodplain (i.e., buyouts) in flood and coastal storm damage reduction planning. In that case, all the services of the new land uses created by removing structure are allowed to be measured and used as benefits towards justifying the costs of removal.

Motivations for Change

The often expressed criticism of civil works planning is that planning studies fail to recognize that the full array of watershed services, and life support services in particular, might be enhanced or diminished by civil works interventions in watersheds; the result is that the effects of plans on some services are not adequately evaluated and considered in plan comparison and selection. There appears to be a concern that the first category of projects described above (NED) continue to be formulated to enhance services that are inputs in production (waterway transportation and flood storage and conveyance), but the evaluation processes do not adequately evaluate and use the estimated effects of plans on life support services in plan comparison and selection (or in setting mitigation requirements for the selected plan). Similarly, the second category of projects described above (NER) continue to be formulated to enhance life support services, but the evaluation processes do not adequately evaluate and use the estimated effects of plans on other watershed services in plan comparison and selection.

Actions for Modernizing Evaluation Practices

Corps planning policy and guidance could address the concerns that appear to motivate the Corps’ critics by: a) acknowledging that plan effects on life support services have standing in plan comparison and selection for all planning studies, and; b) requiring the use of appropriate monetary and non-monetary metrics to evaluate all watershed services that are significantly affected by plans. More specifically, policy and guidance would accommodate the following points:

1. For all services categorized above as inputs in production and direct use services that are significantly affected by plans, require evaluation of all positive and negative effects from changes in service levels using monetary proxies for users’ willingness to pay (WTP) for those changes. Methods and procedures for evaluating such economic benefits are already included in Corps planning guidance, though updates to that guidance will be needed to reflect contemporary circumstances (e.g., deregulation of electricity markets) and economic evaluation technology (e.g., advances made by the Corps’ “Navigation Economics Technology” program).

2. For measuring the effects of plans on life support services, develop and apply appropriate place-based, non-monetary metrics for use in plan formulation, evaluation, and selection, with consideration also given to monetary (WTP) metrics when certain criteria are met.

With regard to point 2, there is much interest in evaluating the effects of plans on as many watershed services as possible using WTP metrics. Some people argue that changes in all watershed services, including life support and associated waste assimilation services, can and should be evaluated in monetary terms in civil works planning, so the that monetary benefits of intervention are directly comparable to the costs. A related argument is that if the effects of intervention on life support services are not evaluated in monetary terms, then these effects will receive less consideration in the decision-making process.

There are several factors that should be considered when deciding when monetary versus non-monetary metrics are appropriate for representing plan effects on some watershed service in a particular planning study. First, the chosen metrics should be capable of being predicted, with an acceptable degree of uncertainty, using the available planning models within study time and budget constraints. This criterion might be termed “predictability.” Second, the metrics chosen should be decision-relevant for the area and central problems of concern where planning takes place, which requires that they be understood by and acceptable to non-federal sponsors and other study participants (who may include more than just representatives of the federal agencies involved in planning). This second criterion might be termed “credibility.” Credibility is not completely independent of predictability, since an estimated performance metric that is characterized by high uncertainty may affect the extent to which that metric is viewed as credible by study participants and decision-makers. However, credibility also addresses other factors, such as whether the metric is intuitively meaningful to study participants (e.g., what is a habitat unit?), which can affect the extent to which different participants may view a metric as decision-relevant and acceptable.

The table below considers four different types of metrics for measuring the effects of plans on life support services, and includes judgments on how they compare against these criteria. (See discussion on watershed services for the logic behind the rows in the table). Of course, the specific judgments made in any planning case would necessarily consider place- and situation-specific circumstances. Note that completing evaluation at the level of rows 2-4 in the table requires drawing upon the result of analysis completed for the rows above it.

Options for Representing Plan Effects on Life Support Services

Basis for Evaluation	Example Performance Metrics	Time & Cost of Analysis	Uncertainty in Estimates	Credibility of Estimates
Hydrologic and Geomorphic Structure & Processes	Change in area of connected floodplain & acres of wetlands; shape of hydrograph	Low	Low	High
Ecological Function	Index of Biotic Integrity; Habitat Suitability Indices for one or a community of species; Direct measure of some stage in the life cycle of a species of interest	Low to Moderate	Low to Moderate	Moderate to High
Service Levels	Direct measures of changes in biodiversity or populations of one or more target species	Moderate to High	High	Moderate to High
Economic Value (WTP)	Alternative cost; Net income; Revealed and stated preferences for use (recreation) and non-use of services	Moderate to High	High	Low to High

To more fully appreciate the implications of the table for plan evaluation, consider as an illustration a planning objective (i.e., problem and opportunity to be addressed by planning) that is focused on a specific species, such as the endangered pallid sturgeon in the Missouri River. In that case, the planning objective might be described as “Increase the population of pallid sturgeon in the Missouri River for 30 river miles above and below Gavins Point Dam." Plan formulation for Corps actions that might contribute to this objective would require the development of a conceptual ecological model to describe how the relative effect of changes to the river's hydrologic and geomorphic structure & processes (row 1 of the table) would contribute to the defined planning objective. The development of the conceptual ecological model would be informed by reference to pallid sturgeon population dynamics in other watersheds that have viable populations and by analysis of past populations of pallid sturgeon in the river segment of interest. Of course, the desire would be to secure that end state in the most cost-effective manner, and the actions to meet that end state may extend beyond those within the authority of the Corps to implement. The conceptual ecological model for the Pallid sturgeon would help to identify the full range of actions required.

One could imagine a series of empirical models, based on the conceptual ecological model outlined above, corresponding to each row in the table, which could be used for evaluating and representing the effects of civil works interventions. For example, one possible intervention might be a series of structures (this could involve setting back a levee) at various locations along the river that reconnect the river to the floodplain with side channels that have certain flow velocities, depths, and other characteristics in order to create spawning areas for pallid sturgeon. The modeling in the first row would predict whether the structures would create such reconnections, and provide estimates of the acres of reconnected floodplain with the specified characteristics. This measure of reconnected floodplain acres might then serve as the metric for representing plan effects on the defined planning objective.

Instead of stopping the evaluation process at row 1 of the table, another model could be employed that uses the estimates of reconnected floodplain acres as one of many inputs to predict change in the quality and quantity of spawning areas for pallid sturgeon. The measure of effect might take the form of an index of habitat suitability for pallid sturgeon spawning. Alternatively, there might be a prediction of how many adults will enter the newly created areas, or spawning success once they enter the areas, or number of young pallid sturgeon that can enter into the river. These metrics relate to evaluation corresponding to row 2 in the table, and could serve as the metrics for representing plan effects on the defined planning objective.

Again, the evaluation process could continue on to modeling corresponding to row 3 and seek to predict growth and survival of the young pallid sturgeon in the river itself. This estimate of increased pallid sturgeon population is most closely related to the specified planning objective, and thus could serve as the metric for representing the effects of intervention.

Finally, evaluation of plan effects could continue further on to the last row and use an economic model that predicts the WTP value of the increase in the pallid sturgeon population resulting from the intervention. For example, the hypothesized value might relate to so called "non-use" preferences representing peoples' WTP to preserve the endangered pallid sturgeon in the Missouri River. In principle, such non-use values could be estimated using hypothetical choice (stated preferences) techniques such as "contingent valuation" that essentially involve structured public surveys that are designed in a way to elicit the choices that survey respondents would make if they had to pay for alternative states of nature. However, there is considerable disagreement over whether individuals' non-use preferences (as well as use preferences) for changes in life support services can be reliably estimated using stated preferences valuation techniques. Many objections to this approach have been articulated outside as well as within the economics profession.

In the specific example used here, which involves an endangered species, the significance of the species as a matter of federal interest is obvious and the nexus between the status of the population and Corps projects on the river is well-established. Therefore the need to monetize its value in order to justify plan formulation and investment by the Corps might be questioned (and is proscribed by current Corps policy). But even if planning in this case were focused on a wildlife species that is not endangered, calculations that trace through how interventions would affect human uses and preference satisfaction would be fraught with uncertainty, and the resulting WTP estimates might not be viewed as credible by at least some stakeholders.

To further illustrate that credibility challenge, consider how the general evaluation options described above might be applied to the choice of metrics for representing plan effects on ecological services (life support and waste assimilation services) when specified problems and opportunities focus on other watershed services. For example, consider a case in which the planning objective is specified as "reduce flood damages in community X," and where formulated plans might also affect ecological services in the watershed. Recall that in such contexts the conceptual framework for Corps planning (in section 4.3.2) calls for the formulation of a "protection and restoration plan" that makes a positive contribution to the defined planning objective while leaving current watershed hydrology unchanged (or restoring past hydrologic and geomorphic processes, when possible). Such a plan formulated to reduce flood damages might involve the restoration of an area of previously drained wetlands located along the river above the community. The extent to which restoration of previously drained wetlands along the river reduces flood peaks in the downstream community (a watershed service) would be estimated, and then the economic value (property damages avoided) calculated using well-accepted Corps procedures.

But how could the effects of plans on ecological services in this case be evaluated and represented? The restored wetlands might also trap nutrients that would otherwise enter the river. The reduced nutrient levels might have a positive effect on oxygen levels in the river, and then on populations of fish species that are prized by sport fishermen. Accordingly, the evaluation of these effects might seek to calculate nutrient reduction in the river (row 2) and then proceed to calculate the effect of nutrient reduction on the recreational fish population (row 3), and then recreational angler use and satisfaction and hence recreational anglers' willingness to pay for the nutrient reduction (row 4). However, that calculation would be characterized by increasing uncertainty with each evaluation step, and the resulting WTP estimate may not be viewed as credible by some stakeholders.

As an alternative to estimating and using complex bio-economic production functions to trace through the effects of plans on human uses and preference satisfaction, the increase in nutrient retention provided by the restored wetlands might be monetized in terms of the avoided costs associated with building a waste treatment facility that could provide the same level of nutrient reduction. However, professional economists and others have long criticized such "alternative cost" measures, since they are viewed as credible proxies for WTP only under highly restrictive conditions that rarely are in evidence.

In the end, different groups of people would make different judgments relating to the credibility of WTP estimates for representing the effects of plans on life support (and waste assimilation) services calculated using the valuation approaches outlined above. This is why the last cell of the table characterizes the credibility of WTP metrics for representing changes in ecological services as ranging anywhere from low to high, where credibility is judged by study participants and decision-makers.

As a general matter, judgments must be made about the preferred metrics for representing plan effects on life support services. Metrics that are based on hydrologic and geomorphic structure and processes, and to a lesser extent metrics based on ecological structure and function, rate best against choice criteria relating to predictability (time and costs of analysis as well as uncertainty) and credibility of estimates. These two evaluation bases have been used most frequently for the choice of metrics for representing plan effects on life support services in NER planning studies. For such metrics to be decision-relevant, however, they must be ecologically-meaningful in the sense that they can be conceptually linked to provision of the relevant life support services in any particular planning case.

As noted earlier, the choice of performance metrics for representing changes in life support services in any particular planning study would necessarily be place-specific and based on the central problems of concern. While metrics based on hydrologic and geomorphic structure and processes or ecological structure and function do not provide a direct representation of life support services, they can be useful for formulation and evaluation since they align with the types of watershed features that give rise to those services, and are generally more predictable and credible than metrics produced by the evaluation steps corresponding to rows 3 and 4 in the table.

That said, Corps policy might be revised to allow for use of any of the evaluation metrics included in the table, including WTP estimates, if the predictability and credibility criteria were met to the satisfaction of study participants and decision-makers. Whatever metric is chosen to represent changes in life support services in any planning case, that metric should be used to measure both positive and negative effects of alternatives on life support services, and to guide the determination of any necessary environmental compensatory mitigation.

Commentary

The need is to select and use evaluation metrics that are decision-relevant for the environments where planning takes place, and acceptable to and understood by non-federal sponsors and other study participants, such as federal resource agencies. Selection of metrics for the full array of affected watershed services is as much a bottom-up process for plan development as it is a top-down process that is directed by national policy and guidance.

Furthermore, given study budget constraints, performance must be measurable and predictable with some confidence using the types of models employed in planning. Of particular note here is that life support services, among all watershed services, has been the most difficult to define uniformly in a metric that is meaningful at a national scale. Further, changes in life support services are the most difficult to predict for a given change made to watershed structure and processes.

An alternative approach that would avoid these problems begins with the recognition that since life support services are closely aligned with natural watershed hydrology and geomorphology, proxy metrics for the effects of alternatives on life support services can be based on predicted hydrologic and geomorphic changes. Changes in these watershed attributes are most directly linked to civil works actions, and thus can be more readily and accurately predicted with an acceptable degree of uncertainty within study budget and time constraints. Such metrics have been successfully used in past NER planning. Metrics based on hydrologic and geomorphic outcomes must be ecologically-meaningful, however, and thus would necessarily be place-specific and based on the central problems of concern.

This approach to evaluating changes in life support services for civil works planning is recommended by the framework, and it would not be a radical departure from past practice. Proxy metrics for life support services based on ecologically-meaningful hydrologic and geomorphic metrics provide decision-relevant planning information in the same way that hydrologic metrics of flood damage reduction (level of protection) or water supply (safe yield) have assisted planning for many years. When such non-monetary metrics are employed, reference conditions for the relevant life support services can serve as a benchmark for comparing plans and deciding when one or more plans are "justified" (see box below).

As for the question of monetization of effects, the framework recommends that for all planning studies, including those that focus on ecosystem restoration, use of monetary metrics for evaluating all significant service changes that can be readily and credibly reported in monetary terms, and for which there is a tradition of employing monetary metrics for evaluation. For example, the monetary benefits of flood damage reduction for some community achieved by wetlands restoration in the watershed would be evaluated and reported in monetary terms in the same way that the flood damage reduction benefits for a levee would be evaluated and reported. On the other hand, for life support and waste assimilation services, the challenges to monetization described above need to be recognized. For this reason the framework leaves the decision on the extent of monetization of service changes, beyond the services that traditionally have been measured in monetary terms, to the participants in the planning collaboration; they can determine for themselves the credibility and hence the decision support utility of such measures.

Reference Conditions for Comparing and Justifying Alternative Plans

The decision-making challenge is to decide how much life support output is justified in consideration of financial and opportunity costs. Current Corps policy eschews monetization to justify a level of life support output. Instead, the District Engineer makes a recommendation on the justified level of output, as informed by cost-effectiveness and incremental cost (CE-IC) analysis. In a simple graphical display, one non-monetary metric of life support output would be displayed on the horizontal axis and net costs on the vertical axis. If the cost curve turns sharply upwards at some point, that inflection point helps to determine when additional units of the life support output may not be warranted by the cost required to achieve it.

However, the CE-IC framework does not define an end point that identifies where a higher level of investment cost to achieve a higher level of life support output is unwarranted. In the case of planning for recovery of an endangered species, such an end point would be a "viable" population that would make de-listing of the species possible. Outside the special case of planning for an endangered species, a possible end point for some life support output might be achieving some watershed reference condition.

Suppose the planning objective is to increase the population of a specific fish species in a river. The reference condition might consider a time in the past when the hydrologic conditions in the river supported what the planning stakeholders agree was a preferred level of the fish species. Based on that reference, a model of the hydrograph for that time could be developed and used to determine hydrologic indicators for representing plan effects on life support services, as well as for defining a target hydrograph corresponding to the preferred level of life support output. However, it does not follow that the recommended plan must meet the target hydrograph (indeed, it may be the case that none of the formulated plans could reach the target). The EC-IC analysis would be done and a judgment would need to be made on whether the incremental costs of plans that provide higher levels of life support output are justified.

End Notes

[1] The evaluation and comparison of alternatives will be against various choice criteria in order to support recommendation of a preferred alternative by multiple decision-makers (non-federal sponsor, District Engineer, Chief of Engineers, Office of Management and Budget, and the Congress). There can be no single bright-line computation that identifies the "best" alternative when there are multiple, non-commensurate choice criteria and multiple decision-makers. Therefore the intent of this framework is to produce a complete and useable display of the multiple and incommensurate measured effects of alternatives in order to best inform those who have the responsibility for choosing a preferred plan and recommending a federal funding contribution for implementing that plan.

[2] NEQ effects are expected to be realized over time and at the watershed scale as a result of plan implementation.

[3] Current Corps planning guidance uses the term "national economic development" effects to represent the economic efficiency implications of plans that lead to a reallocation of natural and human capital in the larger economy. In common understanding, however, that term refers to "economic growth" associated with the productivity of natural and human capital as reflected in changes in employment, wages, rents, and profits. In this framework, this category of effects relates to economic efficiency (rather than economic growth) and is labeled as national economic efficiency effects to avoid potential confusion. Beneficiaries' "Willingness to Pay" (WTP) for project outputs is a measure of economic benefits for economic efficiency evaluation. If infrastructure investments were to be evaluated for their potential to increase economic growth, this would require measures of economic performance that are different than WTP measures. If deemed necessary, further development of the framework could address measures for evaluating the implications of plans for economic growth, recognizing that such growth effects are most likely to be associated with inland navigation and port development planning contexts.

[4] Negative changes are foregone existing benefits (opportunity costs) of the current service flows from the water and related land resources system, including the benefits that currently are realized from the engineering works now in place.

[5] This corresponds to the Environmental Quality "account" in current Corps planning guidance, except that environmental effects at the watershed scale have been separated out for isolation in the new NEQ effects category.

[6] Evaluation of the employment and income effects of alternatives on low income, minority, and tribal communities is the only place in this framework where the evaluation of what current Corps planning guidance calls "regional economic development" (RED) effects are deemed relevant. Other than for this subset of the affected population, RED effects are not relevant as a federal evaluation criterion because such impacts have long been recognized as representing transfers of economic activity rather than national economic efficiency effects.

[7] Scoping in this framework is given added importance relative to how it is addressed in current Corps planning guidance.

[8] An alternative term to describe the need to define the systems of interest would be "planning scope" to emphasize both the geographic and non-geographic elements of the relevant systems.

[9] This is the same watershed scale used when considering the effects of wetlands dredge and fill permitting and compensatory mitigation offsets (e.g., mitigation banking) within the Corps regulatory program.

[10] Consider the analogy of a throw of perfectly balanced dice. In this case there is no knowledge uncertainty because we know that the possible outcomes must be between 2 and 12. However, for any given throw we can only assign a probability to the outcome. Continuing with this analogy, if we were handed the dice and knew little about them we would have knowledge uncertainty (the dice might not be balanced). We could invest in testing the balance of the dice and in so doing reduce knowledge uncertainty. The dice example can be misleading, however. The throw of a dice is a “closed” system, meaning that we may not know the outcome for any throw, but we can place bounds on and assign probabilities to the range of possible outcomes if the dice are balanced. If the system were instead “open,” that would mean that there were many unknown and unknowable external factors that could cause the future outcome to fall outside the range we might expect. Many argue that environmental and economic systems are open systems and so uncertainty due to knowledge uncertainty as well as unbounded natural variability may exist. Some would use this argument to advocate for a precautionary principle decision rule. However, the precautionary principle implicitly favors the status quo, and change may be desired. Beyond the precautionary principle, plan formulation could include redundancy and feedback elements, and a “robustness” criterion might be one decision factor. If incremental implementation were possible and committed to, then adaptive management strategies might be favored.

[11] The reasons path 1 was followed, including but not limited to limited study resources, should be justified. The qualifications of the professionals and experts whose judgments were used to assign values to key parameters and variables should be described.

[12] When forecasting future, without-project conditions when the level of uncertainty in future resource conditions makes it impossible to reasonably bound the range of possible plan outcomes, then scenarios representing different potential future resource conditions should be employed for plan formulation, evaluation, and display. Subsequent evaluations of plan effects would then be made under the different scenarios. When there is evidence that evaluations of plan effects are sensitive to the different scenarios, analysts should report on that uncertainty and provide a written characterization of the premises underlying each alternative scenario that identify what would need to happen for the scenario to be realized (the concept of “premise sets” can be used to achieve this result).

[13] A compelling application of premise-based scenario planning can be found in: U.S. Army Corps of Engineers, Portland District. 1985. Decision Document – Mt. St. Helens, Washington. In-House Document 99-135, December 10, 1985. Communication from the Assistant Secretary of Army (Civil Works). Washington, DC: Government Printing Office.

[14] Gail Bingham, President Emeritus of RESOLVE, contributed to the development of the conceptual logic in this section. Ms. Bingham served as a Senior Fellow at IWR during 2009, has mediated water policy and other natural resources issues for over 30 years, and is the author of numerous publications including, *When the Sparks Fly: Building Consensus When the Science is Contested*.

[15] The concept of "Circles of Influence" can be applied to organize the different options for engagement. http://www.computeraideddisputeresolution.us/bestpractices/circlesofinfluence.cfm

[16] This list is adapted (with significant changes) from: http://www.fermilabcommunity.org/pdfs/spectrum.pdf

[17] A consideration in choosing a level of engagement is the constraints imposed by the Corps' internal review process and the Federal Advisory Committee Act (FACA). If the levels of engagement deemed warranted by IWRM are to be realized, the Corps should review its current internal review polices and interpretations of FACA to maximize the possibility for engagement, and then issue clarifying guidance to its field offices.

[18] This section of the framework is written with only limited attention to the implications of uncertainty and the level and form of agency and stakeholder engagement. Any further development of this framework would need to address how the description of standard planning elements might need to be altered to better incorporate options for addressing uncertainty and agency and stakeholder engagement. For example, if a full "Shared Vision Planning" process for engagement were to be employed, the planning elements and the sequence in which they are addressed might be changed. See: http://www.iwr.usace.army.mil/docs/iwrreports/10-R-5.pdf

[19] This wording is meant to distinguish "objective-based planning" from "target-based planning," although targets based on statements and goals may become constraints on planning (e.g., meeting a water quality standard or securing some minimum level of residual risk) or a focus of planning (ESA requirements). The recognition of such constraints is addressed in plan formulation and can be accommodated in plan evaluation. See: Deason, J.P., Dickey, G.E., Kinnell, J.C. and Shabman, L.A. "An Integrated Planning Framework for Urban River Rehabilitation," Journal of Water Resources Planning and Management, November/December 2010.

[20] Note that in current Corps planning guidance, the list of formulation criteria includes "efficiency" as a fourth formulation criterion. It states, "Efficiency is the extent to which an alternative plan is the most cost-effective means of alleviating the specified problems and realizing the specified opportunities." In effect, efficiency is a way to remove "dominated" (clearly inferior) plans from further consideration. However, the concept of a dominated plan is difficult to apply as an operational matter in the multi-criteria decision setting, at least at this planning stage. See the Phase 1 display discussion (later in framework) where the concept of removing dominated plans from final consideration is addressed.

[21] This formulation criterion will consider preliminary and conceptual determinations of the types and extent of compensatory mitigation that would be needed to offset the adverse environmental impacts at the watershed and sub-watershed scales, as well as any adverse impacts of plans on current watershed uses as part of the acceptability screen.

[22] The issue paper on floodplains, flood risk management and public safety, which is included in Appendix A to this paper, outlines the reasons for formulating a Protection and Restoration Plan when the planning problem and opportunities include flood risk management.

[23] The explicit formulation of a Protection and Restoration Plan (PRP) contributes to creating a consistency between the way that compensatory environmental mitigation plans are developed for civil works planning, and the ways such compensation plans are expected to be developed for permitted dredge and fill projects under section 404 of the CWA. The matter of consistency between the compensatory mitigation planning in these two areas of Corps responsibility is a current focus of concern. However, unlike the 404 permitting context, the conceptual civil works planning framework presented here does **not** dictate selection of the PRP as the preferred alternative.

[24] Note that the purpose of formulating a plan that includes adaptive management elements is to address analytical uncertainty. An adaptive management plan is not one that calls for refining and modifying all elements of the plan over time, which is a process more appropriately called "evolutionary problem solving." More description of the minimum requirements for an adaptive management plan and explanation of the distinction made here between adaptive management and evolutionary problem solving would be provided in any further development of this framework.

[25] This characterization of NEE measurement recognizes that the same NEE effect can sometimes be evaluated in affected input markets (the economic value of water and related land resources) or alternatively, in affected output markets (the economic value of the national output of goods and services produced using water and related land resources). For assessing the benefits of flood damage reduction, however, restrictions on measuring NEE effects in input markets (using land market analysis) are needed because of myriad issues relating to the subjective perceptions of flood risk on the part of land market traders that make this approach conceptually problematic.

[26] The negative changes in the future, without-project condition relative to the reference condition must be the result of past Corps and non-Corps actions, and not be the result of future non-Corps actions. Otherwise, the plan would represent Corps-funded mitigation for non-Corps activities.

[27] For further discussion of NEQ metrics for evaluation, see Appendix B. Substantial additional development of the NEQ metrics discussion is possible and would be required in any further development of the framework.

[28] When applicable, these plan effects will serve as additional considerations in determining the set of plans that are offered for possible recommendation. For example, a GIS mapping with readily available data would allow the analysts to spatially display the risk reduction and residual risk levels (property damages and population at risk) in flood-prone areas, with and without a plan in place. The analyst could then overlay those results with the socio-economic descriptors of those groups located in flood prone areas and display (in map and/or tabular form) how the risk reduction benefits and residual risk to those groups are affected by alternative plans.

[29] This sentence is intended to provide general guidance on the application of monetization to ecological life support services. Further explanation can be found in the issue paper on evaluation included in Appendix B to this paper.

[30] The question of whether to discount NEQ effects in the same way as NEE effects is partly addressed by the requirement to display the time path of NEQ effects.

[31] This section addresses concerns relating to effects of public programs on the NEE calculations; for example, the use of agricultural prices that are significantly influenced by federal agricultural policies.

[32] For example, adverse effects on NEQ and OEQ should each be shown alongside a description of the conceptual compensation plan for these adverse effects as well as the estimated financial costs of implementing the compensation plan. Similarly, any evaluated adverse effects of a plan on existing watershed uses (e.g., recreation), should be shown alongside a description of any conceptual compensation plan for these effects as well as the estimated financial costs of implementing the compensation plan.

[33] The purpose of using the Protection and Restoration Plan as a point of reference for evaluating incremental NEE and NEQ effects is to be responsive to the often expressed criticism that Corps planning does not formulate and consider plans that address problems and opportunities while avoiding adverse impacts on the environment. In many (perhaps most) planning cases, opportunities for fully addressing problems and opportunities while avoiding adverse impacts on the environment may be limited or non-existent. For example, a Protection and Restoration Plan formulated to serve flood damage reduction (e.g., a plan involving permanent removal of structures in one area of a floodplain) may involve unacceptably high residual flood risks for adjacent properties. As another example, a Protection and Restoration Plan for improving deep draft navigation (e.g., a plan involving freight queuing or riding existing tidal changes) may not sufficiently address a defined problem of high harbor access costs for container ships. In such cases, the incremental analysis can help decision-makers to document limitations of the Protection and Restoration Plan for alleviating problems and realizing opportunities, while at the same time use that plan to systematically consider and balance the incremental NEE and NEQ effects of other plans in decision-making.

[34] While the Protection and Restoration Plan serves as a point of reference for Phase 2 plan comparison, and should be carried forward for selection consideration when it meets all formulation criteria, **there is no presumption that this plan should be selected as the preferred alternative**.

[35] Section 3.2.1 (e)(3) describes the different levels of engagement with others in planning. Aside from level 1 (inform), the other levels of consult, involve, collaborate and shared decision-making imply that decisions by the District Engineer on a recommendation of the preferred plan cannot be made in isolation from the preferences of other entities. Ideally, the District Engineer might lead a deliberative process to reach agreement on a preferred plan and organize that discussion around the plan display and comparison information.

[36] Examples of possible aggregate decision criteria include one or more of the following: net NEE, robustness, and NEQ incremental justification. Further identification and explanation of possible aggregation options can be prepared as part of any extension of this framework. In addition, the administration budget process might require certain aggregation results to be reported. However, if aggregation is used and reported in the justification narrative, the report should still include the plan display and comparison information and relate the creation of the aggregation criteria to that information.

Visiting Scholar Program

Maass-White Visiting Scholar Fellowship

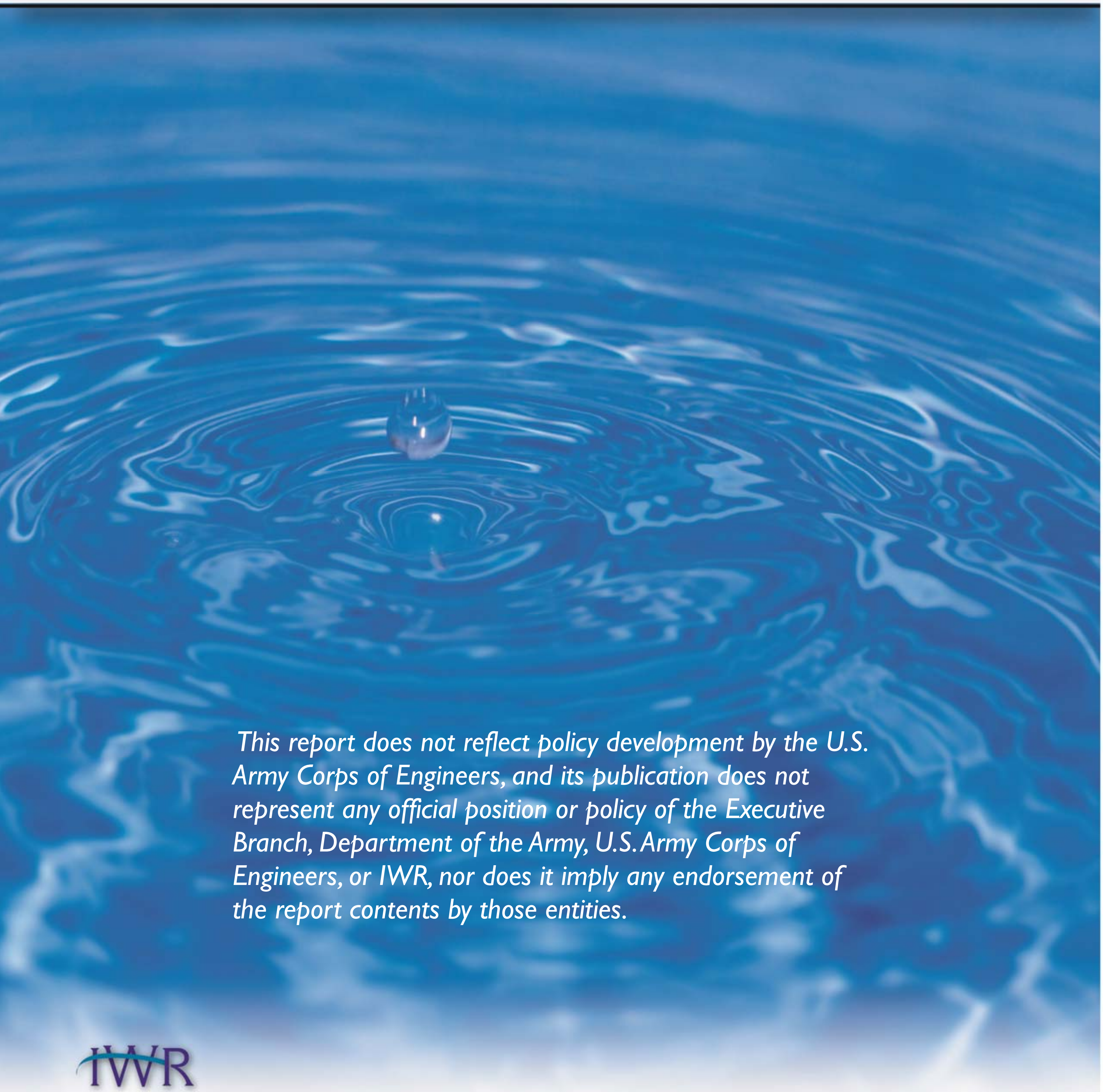
Dr. Leonard Shabman

Dr. Leonard Shabman served as the IWR Maass-White Visiting Scholar during 2004–2006 and since then as IWR Visiting Scholar, where he worked on a variety of activities connected with the overarching theme of water resources planning and policy analysis. Dr. Shabman's primary employment is as a Resident Scholar with Resources for the Future in Washington, DC. He joined Resources for the Future in 2002 after three decades on the faculty at Virginia Tech.

Dr. Shabman has served as a staff economist at the United States Water Resources Council and as Scientific Advisor to the Assistant Secretary of Army. At Resources for the Future his research and communications efforts are focused on programs for flood and coastal storm risk management, design of payment for ecosystem services programs, water quality management under the Clean Water Act, and development of evaluation protocols for ecosystem restoration and management projects, with special focus on the Everglades, Coastal Louisiana and Chesapeake Bay. He served for eight years on the National Research Council's Water Science and Technology Board and has been recognized as an Associate of the National Academy of Sciences.

About the Fellowship

The Maass-White Visiting Scholar Fellowship is designed to ensure that today's water resources challenges benefit from innovative thinking of the nation's top academics, and to promote a deeper understanding of real-world water resource problems by those in academia. The fellowship honors the late Arthur Maass and Gilbert F. White -- two scholars who had a revolutionary impact on the practice of water resources planning and management. Recognizing the importance of scholarship in water resources management, the Institute's Maass-White appointment is offered annually to a scholar whose works promote innovative, substantive reforms in water resources policy, research or analysis. The appointment enables a scholar to work on critical contemporary issues alongside the technical staff of the U.S. Army Corps of Engineer's Institute of Water Resources, either in the Washington DC area or at the Hydrologic Engineering Center in Davis, California.



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PRESENTATION

By Leonard A. Shabman

Engineering Design and Public Safety: Reflections on the Katrina Experience

University of Maryland
Engineering and Public Policy Program
Capstone Course
November 10, 2012

(Presentation notes and PPTS are not available for distribution.)

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Funding and Financing Options for

Funding U.S. Port and Inland Waterways Needs

Leonard A. Shabman

April 2012

White paper included as Chapter 5 in

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U.S. Port and Inland Waterways Modernization:
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U.S. Port and Inland Waterways Modernization

Preparing for *Post-Panamax* Vessels

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FOREWORD

The United States is a maritime nation. From its origin as 13 former colonies to its place as the preeminent world power today, our Nation's success has been dependent on our coastal ports and inland waterways to conduct trade. Recognizing the importance of transportation to trade, the Nation had made a strong intergenerational commitment to develop its transportation networks. From the building of roads and canals in the early days of our Nation, to later construction of the transcontinental railroad and to the creation and development, just within my lifetime, of the Interstate Highway System, the Nation has committed the time and resources to enable and facilitate the large scale movement of raw materials and finished goods from their origin to manufacturer or market, both within our borders and internationally.

These networks of highways, railways and inland waterways connect the interior of our country to our ports, which connect us to the rest of the world. These transportation networks have contributed to our success by providing a cost-efficient and environmentally sustainable means to transport large quantities of cargo over long distances and across oceans, keeping this Nation competitive in world trade.

Population and income drive demand for trade, and trade drives the demand for transportation services. The U.S. population is expected to increase 32 percent, or almost 100 million people, in the next 30 years. The greatest population growth will occur in the South and West. Per capita income is expected to increase 170 percent in the same time period. These increases will drive increased trade, with imports expected to grow more than fourfold and exports expected to grow more than sevenfold over 30 years. The recent U.S. Navy Commercial (http://www.youtube.com/watch?v=EEtZ5r0CIYI), which states that 70% of the world is covered by water, 80% of all people live near water, 90% of all trade travels by water, highlights the importance of waterborne commerce to the Nation and the world.

Our interconnected transportation networks, built in the last century or earlier, resulted in a competitive trade position for this Nation. In order to pass on to future generations the benefits of our competitive trade position, the Nation needs to ensure effective, reliable, national transportation networks and interconnections for the 21st Century. However, as Admiral John C. Harvey, Jr., Commander of the U.S. Fleet Forces Command, put it, "…many of our citizens have taken our maritime services for granted – we are no longer a 'sea conscious' Nation – even though we live in a global economy where 90% of all commerce is still transported by ship…" Despite this, I believe we have an opportunity as a Nation to strategically position public and private investments to become again a world maritime leader.

The Nation is taking steps to seize that opportunity. The Conference Report for the Consolidated Appropriations Act of 2012 (Public Law 112- 74) requested a report from the Institute for Water Resources on how Congress should address the critical need for additional port and inland waterway modernization to accommodate *post-Panamax* vessels. *Post-Panamax* vessels are a reality today. They make up 16% of the world's container fleet, but account for 45% of the fleet's capacity. The efficiencies of scale they provide drive the deployment of more and more of these vessels. By 2030, they are expected to make up 27% of the world's container fleet, accounting for 62% of its capacity. This report provides an analysis of the broad challenges and opportunities presented by the increasing deployment of *post-Panamax* vessels and outlines options on how the Congress could address the port and inland waterway infrastructure needs to accommodate those vessels.

This Nation must address the need and the challenges of a modern transportation system and evaluate potential investment opportunities. This report advances that objective. It contributes to an ongoing public discussion, which is already underway, and will help inform current and future decisions on the maintenance and future development of our ports and waterways and their related infrastructure.

Major General (MG) Michael J. Walsh
United States Army Corps of Engineers
Deputy Commanding General for Civil Works and Emergency Operations

Preface

The U.S. Army Engineer Institute for Water Resources (IWR) welcomed the opportunity provided by the Consolidated Appropriations Act of 2012 (P.L. 112-74) to prepare this report, *U.S. Port and Inland Waterways Modernization: Preparing for Post-Panamax Vessels*. We approached this assignment in a manner befitting the trust and confidence in IWR's work that is reflected in the Committee's designation for this important study.

The resulting document was developed as a true team effort, with the collaborative participation of not only IWR's own in-house specialists and visiting scholars, but also from experts in USACE's various navigation mission specialties from across the organization including the National Planning Centers of Expertise in Deep Draft Navigation and Inland Navigation, located at USACE Mobile and Huntington Districts, respectively, and cost specialists from Walla Walla District and USACE Headquarters. The Institute's efforts were also supported via contracts with the private sector and through a robust public outreach process administered by its Conflict Resolution and Public Participation Center. The Center helped to facilitate openness and transparency as the study progressed, providing public listening sessions and opportunities for input and comment from the navigation community and other interested parties.

Nevertheless, providing advice on "how the Congress should address the critical need for additional port and inland waterway modernization to accommodate *post-Panamax* vessels," as requested in P.L.112-74, implies that the Committee has substantial expectations regarding the certainty and utility of such advice. Let me clarify those expectations at the front and acknowledge that if the history of maritime transportation is any indication – despite what we think we know – uncertainty will persist in the years immediately after the opening of the expanded Panama Canal as to how the Canal's new capacity will specifically drive the future direction of intermodal freight logistics in the U.S., particularly with regard to the timing of the resulting infrastructure needs that will ultimately manifest.

As Christopher Koch, President and CEO of the World Shipping Council, testified earlier this year before the House Transportation and Infrastructure Committee's Water Resources and Environment Subcommittee, "There is neither a single issue nor solution to how to prepare for future maritime transportation infrastructure needs… There is a plethora of studies, opinions and prognostications about what the effects of the new [Panama Canal] locks will be on trade flows, ship sizes, volumes, transshipment port development, and which U.S. ports will benefit by the new locks…It will probably take some years before it is clear exactly what changes to cargo flow, and its supporting transportation network, will result from the new locks."

What we do know is that the world economy is changing, with the pace and scope of these changes accelerating and expanding in unpredictable ways. Shifts in global alliances and political structures, the critical role of emerging technologies, the waxing and waning of the wealth of nations, and even changes to the climate and the natural environment that are impacting agricultural production and the availability of water, are all manifesting right before our very eyes.

But that is the challenge – often we don't pick up the signals that announce many of these changes, nor truly appreciate the significance of the shifts while they are happening or understand the long-term implications associated with these permutations. It is only later, in retrospect, that we recognize some of these changes as transformative "game-changers" to the status quo we mistakenly assumed would continue into the future ad infinitum.

In fact, although many now trace the existence of today's modern containerships to the vision of American truck magnate Malcom McLean, who deployed the first container vessel in the U.S., the converted T2 tanker *Ideal X*, who among us realized that when the *Ideal X* carried 58 containers from Port Newark, NJ to Houston, TX on its maiden voyage on April 26, 1956 that we were witnessing the beginning of a revolution in modern shipping that represented a mega-shift in world trade? In his book "*The Box*," author Marc Levinson points out that "absolutely no one anticipated that containerization would open the way to vast changes in where and how goods are manufactured, that it would provide a major impetus to transport deregulation, or that it would help integrate East Asia into a world economy that previously had centered on North America."

By undertaking the current expansion, Panama will double the Canal's capacity. The resulting economy of scale advantage for larger ships will likely change the logistics chains for both U.S. imports and exports. Despite the uncertainties in timing and port-specific implications that still need to play out, the certain injection of successive new generations of *post-Panamax* vessels into the world fleet could be a "game-changer" for the U.S. over the long term, as it has the potential to not only provide a cost-effective complement to the intermodal transport of imports via the U.S. land bridge, while also re-shaping the service from Asia to the Mediterranean and on to the U.S. East Coast, but may also affect the highly competitive transport price structure along the Midwest to Columbia-Snake route for grain and other bulk exports bound for trans-Pacific shipping. Inland waterways play a key role in the cost efficient transport of grains, oilseeds, fertilizers, petroleum products and coal. Gulf ports play key roles in the transport of these commodities, such as New Orleans being the dominant port for the export of grains from the U.S. Therefore the expanded canal could provide a significant competitive opportunity for U.S. Gulf and South Atlantic ports and for U.S. inland waterways – if we are prepared.

Through effective planning and strategic investment the U.S. can be positioned to take advantage of this opportunity. The railroad industry has been investing $6-8 billion a year over the last decade to modernize railways and equipment, and U.S. ports plan public and private-sourced landside investments of the same magnitude over each of the next five years. Annual spending on waterside infrastructure has been averaging about $1.5 billion.

While the U.S. has ports on the West Coast (Los Angeles, Long Beach, Oakland and Seattle/Tacoma) and East Coast (New York, Baltimore and Hampton Roads) expected to be ready with *post-Panamax* channels in 2014, there is currently a lack of *post-Panamax* capacity at U.S. Gulf and South Atlantic ports – the very regions geographically positioned to potentially be most impacted by the expected changes in the world fleet. The Corps currently has 17 studies investigating the opportunity to economically invest in deep draft ports. At the Port of Savannah, USACE has identified an economically viable expansion to accommodate *post-Panamax* vessels. This project is estimated to cost $652 million dollars. It is possible that several of the remaining studies will also show economic viability and, if so, the challenge will be to fund these investments. In addition, justified investments in inland waterway locks and dams will be needed to allow the waterway transport capability to take advantage of an expanded canal for U.S. exports. This emphasizes the strategic need to address the revenue challenge within the Inland Waterway Trust Fund.

Given this opportunity presented by the deployment of *post-Panamax* vessels, it is critical that the U.S. develop and move forward with a strategic vision for a globally competitive navigation system that sets the context for ensuring adequate investment in maintaining current waterside infrastructure and also facilitates the strategic targeting of investments to ensure the U.S. is ready for *post-Panamax* vessels and "cascade" fleet deployments consistent with the growth in global trade that is anticipated over the next twenty years.

Constrained Federal funding both for harbor channels and inland waterways can be expected due to overall economic and fiscal conditions and concerns about the deficit. This underscores the need to consider new and innovative public and private funding sources and financing methods with long-term reliability that can finance the navigation system maintenance and expansion that will be necessary to ensure a globally competitive U.S. navigation system. The Institute stands ready to support USACE, the Administration and Congress in realizing this 21st Century vision.

Robert. A. Pietrowsky
Director, Institute for Water Resources

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Executive Summary

"The potential economic gains from trade for America are far from exhausted. Roughly three quarters of world purchasing power and almost 95% of world consumers are outside America's borders... Trade remains an engine of growth for America."

Office of the United States Trade Representative
http://www.ustr.gov/trade-topics/economy-trade

The health of the U.S. economy depends, in part, upon the vitality and expansion of international trade. International trade depends upon the Nation's navigation infrastructure, which serves as a conduit for transportation, trade, and tourism and connects us to the global community. Marine transportation is one of the most efficient, effective, safe and environmentally sound ways to transport people and goods. It is a keystone of the U.S. economy. Ninety-five percent of our international trade moves through the Nation's ports.[1]

Cargo carriers, seeking to service this global trade more efficiently and lower costs, are commissioning the building of ever larger ships, known as *post-Panamax* vessels. These vessels are currently calling at U.S. ports and are expected to call in increasing number. The completion of the Panama Canal in 2014 will influence the timing of their arrival at certain ports. However, *post-Panamax* vessels will dominate world trade and call at U.S. ports regardless of the Panama Canal expansion as they are expected to represent 62 percent of total container ship capacity by 2030.

How the Nation invests in the maintenance and modernization of its navigation infrastructure presents financial challenges to be met and economic opportunities to be seized. Sustaining a competitive U.S. navigation system that can enhance economic opportunities for future generations without significant harm to the environment will require a coordinated effort between government, industry and other stakeholders.

Identifying Capacity Maintenance and Expansion Issues Associated with *post-Panamax* Vessels

Congress directed the USACE Institute for Water Resources to submit to the Senate and House committees on appropriations a "report on how the Congress should address the critical need for additional port and inland waterways modernization to accommodate *post-Panamax* vessels." This report fulfills that request. This report identifies capacity maintenance and expansion issues associated with the deployment of *post-Panamax* vessels to trade routes

[1] Complete Statement of the Honorable Jo-Ellen Darcy, Assistant Secretary of the Army (Civil Works) before the Committee on Transportation and Infrastructure, Subcommittee on Water Resources and Environment, United States House of Representatives, on the Economic Importance of Seaports: Is the United States Prepared for 21st Century Trade Realities – October 26, 2011

serving U.S. ports. This identification has been accomplished through an evaluation of the future demand for capacity in terms of freight forecasts and vessel size expectations and an evaluation of the current capacity of the Nation's inland waterways and coastal ports.

Despite the recent worldwide recession, the expected general trend for international trade is one of continued growth as the world's population and standard of living grow. As international trade expands, the number of *post-Panamax* vessels is expected to increase. The Nation's ability to attract these vessels and allow efficient use of their capacity is the key to realizing the transportation cost savings these vessels represent. For example, the Corps investigation of the Port of Savannah indicates a $652 million dollar investment where the benefits far exceed the cost.

Growth is expected in overall trade and deployment of *post-Panamax* vessels to U.S. ports is certain for multiple trade routes. The expansion of the Panama Canal, currently underway, will accelerate the timing of the deployment of these vessels to more U.S. ports. There is, however, uncertainty in the port specific details: at which ports they will call; when these vessels will arrive in large numbers; how deep these vessels will draft arriving and departing; and the supporting infrastructure needed (channel depth and width, number and sizes of cranes, size of available container storage area). Despite the lack of port specific certainty, the Nation can move forward identifying individual projects using established risk informed decision making methods.

The Panama Canal expansion is scheduled to be completed in 2014 and will double its existing capacity. The new locks will be able to pass vessels large enough to carry three times the volume of cargo carried by vessels today. The availability of larger, more efficient vessels passing though the new locks on the canal is expected to potentially have at least three major market effects. (1) Currently, there is significant freight shipped to the eastern half of the United States over the intermodal land bridge formed by the rail connections to West Coast ports. The potential for reduced cost of the water route through the canal may cause freight traffic to shift from West Coast to East Coast ports. (2) To take full advantage of the very largest vessels that will be able to fit through the expanded canal but may be too large to call at most U.S. ports, a transshipment service in the Caribbean or a large U.S. port may develop. The largest vessels would unload containers at the transshipment hub for reloading on smaller feeder vessels for delivery to ports with less channel capacity. (3) On the export side the ability to employ large bulk vessels is expected to significantly lower the delivery cost of U.S. agricultural exports to Asia and other foreign markets. This could have a significant impact on both the total quantity of U.S. agricultural exports and commodities moving down the Mississippi River for export at New Orleans.

There is uncertainty in the port specific details of when such vessels will arrive in large number, which ports they will call, how deep vessels calling will draft and, consequently, how deep navigation channels must be. Over time these uncertainties will reduce as experience replaces expectation. Even in the face of this uncertainty, individual ports are actively engaged in port expansions and studies to deepen and widen Federal access channels. We can predict that in the absence of transshipment centers *post-Panamax* vessels will call in large numbers, they will call at most major ports and their sailing drafts will become known. Our challenge is to invest in capacity expansion in the right places at the right time consistent with industry needs.

Port capacity depends upon channel depths, channel widths, turning basin size, sufficient bridge heights, and port support structures such as dock and crane capacity to offload and onload goods. The deepest channel requirements are likely to be driven by "weight trade" services. Vessels can be filled to their weight capacity or their volume capacity. Vessels loaded to their weight capacity sail at their maximum design draft; they sit deeper in the water. For volume trade routes, channel width and turning basin size may be of greater importance than additional channel depth at some ports, as vessels loaded to their volume capacity often sail at significantly less than their design draft. The Asian export trade is considered a "cube trade" (i.e. volume trade). Careful consideration is needed when determining channel depth requirements at U.S. ports for this trade route.

> "I've talked a lot about the expansion of the Panama Canal in the last couple of years...but the one thing I've learned is that nobody really knows what's going to happen."
>
> –Ricky Kunz, Port of Houston Authority's vice president for origination, as quoted in the *New York Times*, February 18, 2012.

Post-Panamax Ready

For this report, a port is considered "*post-Panamax* ready" if it has a channel depth of about 50 feet with allowances for tide, as well as sufficient channel width, turning basin size, dock and crane capacity. U.S. West Coast ports at Seattle, Oakland, Los Angeles and Long Beach all have 50-foot channels. Northeastern U.S. ports at Baltimore and New York have or will soon have 50-foot channels. In the Southeast, Norfolk has 50-foot channels. South of Norfolk along the Southeast and Gulf Coasts there are no ports with 50-foot channel depths, although Charleston with a 45 foot channel depth and nearly 5 feet of tide can accommodate most *post-Panamax* vessels. This is also the region with the greatest forecast population and trade growth.

Cascade Effect

A system vision should extend beyond the major ports to include lower tier ports. New, large vessels are typically deployed on the longest and largest trade service – Asia to Northern Europe. The "smaller" vessels on that service re-deploy to the next most efficient service for that vessel size. Cascading typically increases average vessel size for each trade service. A navigation system vision should address this cascade effect and its impact on infrastructure for shallower ports. Analysis of individual ports will determine whether the port will need to accommodate *post-Panamax* vessels or the cascade effect.

Remaining Globally Competitive

To remain competitive in a changing global trade market, the U.S. would need to continue making the justified investments necessary to maintain and improve its navigation transportation infrastructure where it is appropriate and efficient to do so. Understanding the current funding challenges and making long-term plans for operations and maintenance (O&M) and justified investments are critical to developing an effective vision for a competitive navigation system.

USACE Civil Works appropriations to address waterside infrastructure have averaged about $1.5 to $2 billion per year for the last decade. These expenditures have been used to maintain, construct and improve the most highly justified inland and coastal navigation infrastructure projects, and reflect the nation's most efficient navigation investment strategy.

To accommodate expected increase in agricultural exports through the Gulf, the current inland waterways must be adequately maintained through maintenance dredging and justified major rehabilitation.

USACE currently has 17 active studies investigating possible port improvements, most associated with the desire to be *post-Panamax* ready. One such study at the Port of Savannah is nearing completion and indicates an economically justified project that will cost about $652 million. It is likely that other studies will also show economically justified projects, either to become "*post-Panamax* ready" or "cascade ready." The preliminary estimate to expand some ports along these two coasts was about $3-$5 billion. Specific investments in ports must be individually evaluated for their timing and economic and environmental merits.

Financing Options

Addressing "the critical need for additional port and inland waterway modernization to accommodate post-Panamax vessels" necessitates an examination of the current delivery mechanisms, the identification of issues and the offering of options for the future. Among the issues identified, securing funding sources to take advantage of modernization opportunities in a timely manner, given the constrained fiscal environment, was judged the most critical. A notional list of financing options is presented to initiate discussion of possible paths to meet this challenge—it is anticipated that a variety of options may be desirable, and in all cases individual project characteristics, including its economic merits, would need to be considered in selecting the optimal financing mechanisms. These options are illustrative only and do not necessarily represent any Administration, USACE or IWR position. Some options include:

- Coastal ports
  - Increase Federal appropriations in the USACE budget for harbor maintenance and improvements while maintaining current cost share responsibilities.

- Increase Harbor Maintenance Trust Fund (HMTF) user fees and allocate increased revenues to harbor improvements.
- Maintain or increase Federal appropriations and also increase local cost share requirements.
- Encourage individual port initiatives by phasing out the HMTF, expecting individual ports to collect their own fees and make their own investment and maintenance decisions.

- Inland waterways
  - To support waterway improvements, increase the fuel tax and provide increases in Federal appropriations to track with the increased revenues flowing into the IWTF; depending upon the revenues from the fuel tax, reduce the share of total costs that is paid from general appropriations.
  - Replace the fuel tax with a vessel user fee and/or combine the fuel tax with a vessel user fee and increase revenues and appropriations for improvements at least by the amount of the increased revenues[2].
  - Implement public-private partnerships with the responsibility for improving, operating and maintaining the inland waterway navigation infrastructure along specified segments of the system. Financing for these actions would be secured in private capital markets with revenues to repay the financed activities earned from a combination of vessel user fees (segment fees or lockage fees) and appropriations.

Regardless of the Federal government's role in funding future navigation improvements, maintenance and operations, USACE will continue to have an environmental regulatory oversight responsibility. Under most options USACE will continue its responsibility for performing environmental assessments and developing environmental protection and mitigation plans. However, if individual ports choose to proceed on their own with harbor deepening projects then USACE would need to provide permits for any proposed action.

Environmental Impacts

Since the 1970s, compliance with the National Environmental Policy Act (NEPA), Clean Water Act, Endangered Species Act (ESA) and other regulatory law has greatly reduced the adverse environmental impacts of many previous practices and positively transformed social attitudes toward the environment. Due to these changes in national commitments, future modernization actions that would have significant adverse impacts will be mitigated, often at great expense, and will play an important role in modernization decisions. In this section, the "environmental footprint" caused by the transportation system is first described to help identify the potential for future environmental impact and mitigation needs. Then indicators of potential impact

[2] The Administration transmitted a legislative proposal to the Congress to reform the laws governing the Inland Waterways Trust Fund as part of the Jobs Bill proposal in September 2011.

sources and vulnerabilities are compared to determine which regions may require the most impact mitigation as a consequence of modernization.[3]

The Environmental Footprint

The national footprint of adverse environmental impacts has accumulated over many decades and is not indicative of the present rate of adverse impact, which is much improved. Measured in geographical terms, the environmental footprint directly impacted by development of transportation system infrastructure is a small fraction of the conterminous United States. But the degree of adverse impact on natural systems and wild species of public interest has been particularly intense and the offsite impacts on air, water and habitat quality from systems operations have been far reaching. The sources of past environmental effects indicate the type of future modernization impacts that are likely to occur from expansion of harbor, port and intermodal infrastructure and from transportation systems operations. Modernization will need to be accompanied by justified mitigation to avoid further 1) degraded air and water quality that threatens human health and safety, especially of low income and minority groups; 2) loss of important natural and cultural heritage found in parks, refuges, wetlands and scarce species; or 3) loss of recreational, commercial and other economically important resources.

Potential infrastructural development along coasts and waterways is a concern because coastal ports and inland waterway infrastructure is closely associated with two of the scarcest types of ecosystems—free flowing rivers and estuarine wetlands. Lock and dam impoundments have contributed substantially to the imperilment of numerous freshwater species by reducing free-flowing river habitat. In general, dredging of nontoxic bottoms impacts coastal and riverine benthic organisms temporarily and bottoms typically recolonize quickly following disturbance. In the past, about 10 percent of bottom sediments were contaminated with toxic materials and resistant to colonization by some bottom species. Sediment toxicity directly affects bottom species and indirectly affects the fish and other species that feed on them and humans at the end of the food chain. Contaminated sediments are now disposed of in isolated containment areas. In 1992, USACE was authorized to beneficially use dredge material for environmental improvement. Today about 20 to 30 percent of port and waterway dredged material is used for habitat creation and other beneficial use. But dredging also has had some persistent effects, including some unavoidable take of imperiled species (e.g., sea turtle take is about 35 per year) and damage to shallow-water estuarine ecosystems. Deepening coastal navigation channels can also favor destructive saltwater intrusion into freshwater ecosystems and domestic water supplies.

With respect to operations, future emissions of potentially harmful materials into air and water, including green house gasses, also are a significant environmental concern. Because harbors concentrate transportation system operations in densely populated areas, they remain a significant source of air quality degradation and inequitable impact on low income and minority

[3] Please see the main report for *U.S. Port and Inland Waterways Modernization: Preparing for Post-Panamax Vessels,* Chapter 4: Environmental Impacts of Capacity Expansion, for references.

groups (which is inconsistent with Federal policies pertaining to environmental justice). Trucks contribute much more than any other mode to atmospheric emissions. In general, relying more on oceanic shipment by large vessel and inland shipment by train and waterway in place of truck transport is preferred because trucks are so much less fuel and emissions efficient. Ports have made improvements to reduce emissions and are planning more, consistent with social concerns. As freight transport operations increase, accidents may increase. Accidental collision of whales and other marine mammals with vessels approaching and leaving ports has been a significant mortality source, but may moderate with recent speed restrictions. Potential oil and other contaminants spills are associated with all modes.

Potential Regional Impact Differences

Past vulnerabilities and adverse impacts revealed in the transportation system footprint of ports and harbors informed selection of 11 indicators of potential impact, which was assessed regionally. These indicators reveal the potential for somewhat greater environmental impact in the Southeast Atlantic Region and, to less extent, in the Pacific Region. Freight transport is expected to grow most rapidly in those regions because of high regional population growth rate. In the Southeast, more harbor expansion is needed to accommodate the largest vessel sizes. In addition, in the Southeast Atlantic Region environmental impact mitigation may be more costly because of greater wetland and endangered species vulnerability. In the Pacific Region mitigation may be more costly due to greater vulnerability of economically important water resource use and low income and minority communities. The Northeast Atlantic Region was ranked lowest because it has the slowest population growth, the greatest amount of unused port capacity, and the least vulnerability to loss of wetlands, parks and other preserves, and threatened and endangered species. The Gulf Region was not ranked quite so low because of its high regional population growth rate, less unused port capacity and greater vulnerability to wetland and endangered species losses.

> "Factoring in environmental and public health costs needs to be part of the decision making process at every step in order to ensure future sustainability of our ports, our coastline, and our population."
>
> –Environmental Defense Fund

The effects of Panama Canal expansion have the potential to redistribute some freight transport growth from Pacific Coast ports to Southeastern ports, raising their impact level as increased impact at Pacific ports fall somewhat. The canal expansion may also favor more transport of grains and soybeans on the Upper Mississippi and Illinois Rivers, increasing the need for lock maintenance. Adverse impacts from possible lock rehabilitation are expected to be minor except for the potential need to mitigate unavoidable loss of riparian wetlands. Some positive effects on air emissions are expected because of less time needed in lock transit.

Adaptive management is a wise strategy to use for future modernization, given the uncertainties held in future modernization actions and mitigation costs, which depend on specific locations, types of actions taken and other unknowns.

Non-Financial Considerations

There are many non-financial factors to be considered when modernizing the Nation's navigation infrastructure:

- A modernization strategy should be part of a national transportation strategy that considers multi-modal connectivity and capacity of the intermodal freight transportation corridors. This would necessitate consistency with other Federal programs such as DOT Tiger Grants.
- Navigation infrastructure modernization will have environmental impacts that will most likely require impact avoidance or replacement of lost environmental quality. Total avoidance of impact may be indicated where the effects are of such national significance that development of transportation infrastructure at the proposed site should not be supported at the Federal level.
- Opportunities to contribute to the Administration's initiative to increase exports, energy independence and enhance national security should be considered.
- Local sponsor commitment in terms of cost sharing and community support should be taken into consideration.
- Consideration should be given to ports that facilitate traffic to multiple regions of the country as opposed to serving only a local catchment area.
- When infrastructure projects are planned, designed and implemented, they should explicitly include the concept of adaptive management (i.e., the identification of sequential decisions and implementation based on new knowledge and thresholds) within a risk management framework.

Who Benefits?

Who benefits from deep water port and inland waterways maintenance and enhancement? The use of larger ships will provide economies of scale to the ocean carriers. These cost savings might be shared with the shippers, the producers and, ultimately, with consumers.

However, it should be noted that the portion of traffic transiting the Panama Canal will also benefit the Panama Canal Authority (ACP). In fact it may be possible for the ACP, through its toll structure, to extract a majority of the benefits on routes that use the canal, limiting the cost savings associated with the use of larger vessels through the canal that will be available to carriers, shippers, producers or consumers. A careful understanding of this is required when choosing which ports to deepen and how to finance the project.

Ports could benefit from increased freight moving through them. As noted, reduced costs for an all-water route from Asia to the East Coast could cause a shift of some market share from the West Coast ports to the East Coast. However, given the expected overall increase in trade, it is not a zero sum game and it is possible that even if West Coast ports were to lose some market share, they will still see an increase in cargo moving through their ports. Moreover, West Coast ports and their rail partners are investing heavily to increase the capacity and efficiency of the intermodal land bridge to ensure it remains competitive and retains market share.

Transshipment might offer some cost savings to cargo headed for ports that are not *post-Panamax* ready. However, transshipment hubs add time and extra handling, costs that may exceed the benefits of using a larger vessel.

The opportunities for reduced costs available to U.S. agricultural exporters through the use of larger bulk carriers are also available to their competitors in international markets.

What seems certain is that some mix of these impacts will be realized gradually over time as market participants gain better certainty of the options they face.

Additional Thoughts

A modernization strategy should be part of an overall national intermodal freight transportation strategy. While the three dominant freight carrier modes – water, rail and truck – compete for market share, there is a growing recognition of the need for multi-modal linkages and for infrastructure investments to be coordinated across the modes to ensure that they complement each other and ensure the best overall use of the available funds for the Nation. This can be supported by prioritizing navigation investment according to their multi-modal connectivity. On March 1, 2012 USACE signed a Memorandum of Understanding with the Department of Transportation on collaboration with a purpose to identify and capitalize on opportunities to improve the Nation's transportation infrastructure investments where shared equities exist.[4]

A national intermodal freight transportation strategy could also consider local sponsor commitment in terms of cost sharing and community support. Opportunities to contribute to the Administration's initiative to increase exports, energy independence and enhance national security must be considered.

[4] See appendix C for a copy of this MOU.

Report Observations and Findings

The main observations and findings of the report are as follows:

- World trade and U.S. trade is expected to continue to grow.
- *Post-Panamax* size vessels currently call at U.S. ports and will dominate the world fleet in the future.
- These vessels will call in increasing numbers at U.S. ports that can accommodate them.
- Along the Southeast and Gulf coast there may be opportunities for economically justified port expansion projects to accommodate *post-Panamax* vessels.
  - This is indicated by an evaluation of population growth trends, trade forecasts and an examination of the current port capacities.
  - Investment opportunities at specific ports will need to be individually studied.
- The potential transportation cost saving of using *post-Panamax* size vessels to ship agricultural products to Asia, through the Panama Canal may lead to an increase in grain traffic on the Mississippi River for export at Gulf ports.
  - An analysis indicated the current Mississippi River capacity is adequate to meet potential demand if the waterways serving the agricultural export market are maintained.
  - A need for lock capacity expansion is not indicated.
- Despite the uncertainty in market responses to the deployment of *post-Panamax* vessels and the expansion of the Panama Canal, individual investment opportunities for port expansion can be identified using established decision making under uncertainty techniques. Adaptive management techniques can also be used to address uncertainty issues. Preliminary estimates indicate the total investment opportunities may be in the $3-$5 billion range.
- Environmental mitigation costs associated with port expansion can be significant and will play an important role in investment decisions.
- The primary challenge with the current process to deliver navigation improvements is to ensure adequate and timely funding to take advantage of potential opportunities.
  - A notional list of financing options is presented to initiate discussion of possible paths to meet this challenge—it is anticipated that a variety of options may be desirable, and in all cases individual project characteristics, including its economic merits, would need to be considered in selecting the optimal financing mechanisms.

Introduction

The United States, its navigation industry and the customers it serves face a potential opportunity. The continued expansion of international trade combined with the building of ever larger ships is reducing ocean transportation costs. However, the extent to where these larger vessels will call at U.S. ports will depend on many factors, including the strategic decisions made by the industry and the Nation, as well as decisions made by the Panama Canal Authority and other parties.

The Committees on Appropriations of the Congress have asked the U.S. Army Engineer Institute for Water Resources (IWR) to submit a report on "how the Congress should address the critical need for additional port and inland waterways modernization to accommodate *post-Panamax* vessels." This report identifies the needs and presents options for meeting the infrastructure needs for U.S. ports and inland waterways.

Post-Panamax vessels will call at U.S. ports in increasing number, either across the Atlantic or through the Panama Canal. How will this affect trade to the U.S., especially along the East and Gulf Coasts? To understand this, we first need to understand that some U.S. ports are already able to accommodate these vessels and others will soon be able to do so. We then need to consider the condition and capacity of some of our other major ports, in order to understand why they do not and will not soon be able to accommodate these vessels. Finally, we will need to consider the condition and capacity of the multi-modal infrastructure that supports cargo movements to and from all of these ports.

There is uncertainty concerning the way in which markets will respond to the deployment of *post-Panamax* vessels. However, with a general picture of the current condition and capacity of our major ports and the multi-modal infrastructure that serves them we can begin to understand the extent to which these vessels may provide an opportunity for further investment, so that options can be developed to move forward.

Given the time available to complete this report, IWR relied on currently available data and could not assess impacts through techniques such as the analysis of specific economic and environmental impacts or the economic modeling of alternative future scenarios.

Congressional Direction

Conference language from Public Law 112-74, the Consolidated Appropriations Act of 2012 (H.R. 2055): Within the funds provided, the Institute for Water Resources is directed to submit to the Senate and House Committees on Appropriations within 180 days of enactment of this Act, a report on how the Congress should address the critical need for additional port and inland waterway modernization to accommodate post-Panamax vessels. This study will not impede nor *delay port or inland waterway projects already authorized by Congress. Factors for consideration should include costs associated with deepening and widening deep-draft harbors; the ability of the waterways and ports to enhance the nation's export initiatives benefiting the agricultural and manufacturing sectors; the current and projected population trends that distinguish regional ports and ports that are immediately adjacent to population centers; the availability of inland intermodal access; and the environmental impacts resulting from the modernization of inland waterways and deep-draft ports.*

About the Study Author

The U.S. Army Engineer Institute for Water Resources is a field operating activity under the staff supervision of the Deputy Commanding General for Civil and Emergency Operations and the Director of Civil Works, Headquarters, U.S. Army Corps of Engineers. The Institute is the USACE knowledge center for integrated water resources management (IWRM) and is specifically recognized as a national expertise center for planning methods, risk analysis, hydrologic engineering, conflict resolution and public participation, international water resources, global climate change science, and the collection, management and dissemination of Civil Works and navigation information, including the Nation's waterborne commerce data.

IWR was established by the USACE Chief of Engineers in 1969 with the approval of the House and Senate Appropriations Committees and the Subcommittees on Public Works in order "to enhance the capability of the Corps of Engineers to develop and manage the Nation's water resources, within the scope of the Corps' responsibilities, by developing essential improvements in planning to be responsive to the changing concerns of our society."

The Institute's mission is to facilitate the adaptation of the Civil Works program to future needs by providing USACE with the capability for developing forward-looking analysis and state-of-the-art methodologies. IWR fulfills this mission by supporting the Civil Works Directorate and USACE Major Subordinate Commands (MSCs) and District offices by providing: (a) analysis of emerging water resources trends and issues; (b) state-of-the-art planning, hydrologic engineering and risk assessment methods, models, training and custom applications; and (c) national data management of results-oriented program and project information across Civil Works business lines.

The Institute is a member of the Federal Laboratory Consortium for Technology Transfer (FLC), a nationwide network of over 250 Federal institutions chartered by the Federal Technology Transfer Act of 1986. IWR also has a cooperative relationship with the National Institutes for Water Resources (NIWR), which represents 54 state and U.S. territorial university-based water centers through the U.S. Department of the Interior and U.S. Geological Survey (USGS). The FLC and NIWR provide USACE with the framework for developing technology transfer strategies and opportunities by promoting and facilitating technical cooperation in cooperation with USACE Districts and expertise centers and among Federal laboratories, industry, academia, and state and local governments.

What Is Navigation Infrastructure?

For this report, the term navigation infrastructure refers to the basic facilities required for safe and efficient vessel movement and handling. This infrastructure includes:

For coastal ports

- channels (including harbor entrance channels, port channels, ocean-route canals and connecting channels)
- turning basins
- navigation jetties
- dredge material placement facilities
- berthing facilities (docks, dredged berths and anchorage areas)
- aids to navigation (channel buoys, global GPS, AIS and updated charts)

For inland waterways

- channels
- locks and dams
- channel training structures
- dredged material placement facilities
- tow marshalling areas
- berthing facilities (docks, dredged berths and anchorage areas)
- aids to navigation (channel buoys, global GPS, AIS and updated charts)

These lists are not exhaustive but are generally representative of the facilities included in navigation infrastructure. Other infrastructure, such as cranes, storage yard space and intermodal transfer connections are critical to the efficient movement of cargo, but are not considered navigation infrastructure.

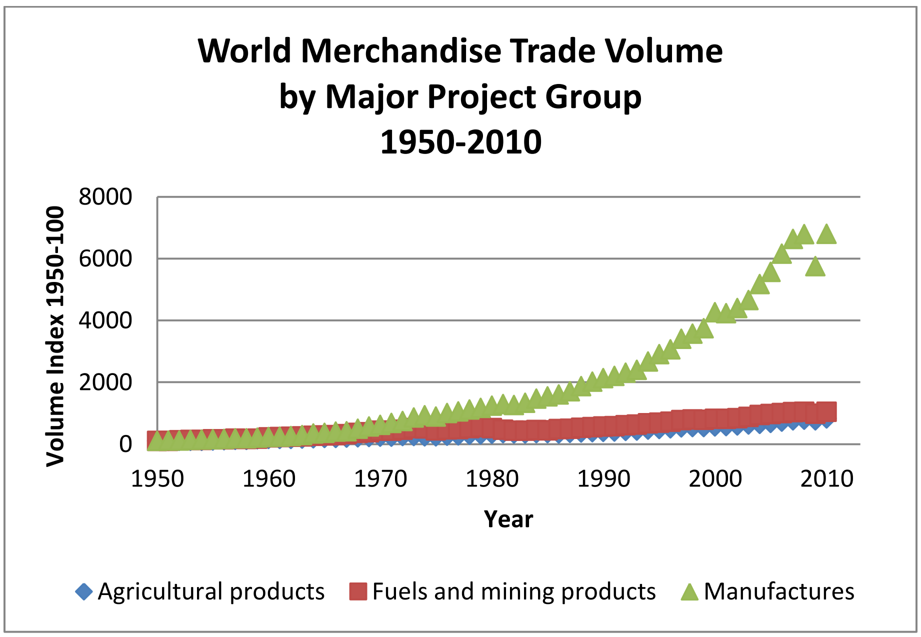
Acknowledgement

IWR thanks the U.S. Department of Transportation, Maritime Administration (MARAD) for their selfless cooperation and sharing of their work.

Chapter 1: Discussion of Demand for Future Capacity

The demand for future capacity within the U.S. freight transportation system is dependent on the volume of future trade. Transportation service is often referred to as a derived demand because it is the demand for goods and services that creates the demand for trade and, thus, for transportation services. For example, the level of world trade determines the demand for international transportation services.

The history of world trade has generally been one of expansion. The volume of world trade has increased about 100 fold (Figure 1) since 1950 according to the World Trade Organization.[5] Trade in agricultural products increased at an average annual rate of 3.6 percent between 1950 and 2011, fuels and mining products at 4.0 percent and manufactures at 7.3 percent. As populations and incomes increase globally, the opportunity and desire for trade expands. In this broad sense, the future is expected to look like the past.



Source: World Trade Organization; International Trade Statistics. 2011

Figure 1: World Merchandise Trade Volume

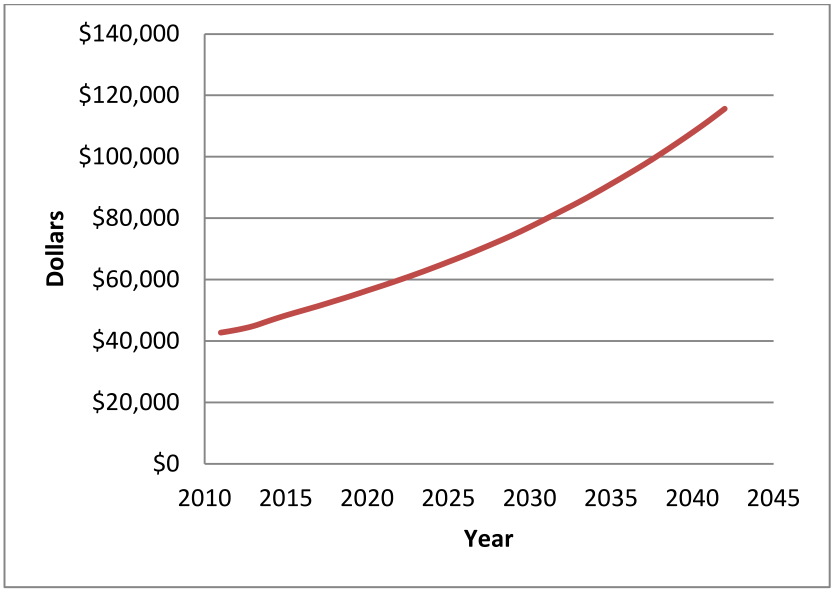
U.S. Population and Income

While global population and income expand world trade, population and income within the U.S. also influence trade volumes and patterns. The overall forecasts of U.S. income and population indicate support for increased demand for transportation services.

[5] World Trade Organization. 2011. International trade statistics.

Projections for Increases in U.S. Income Are Dramatic

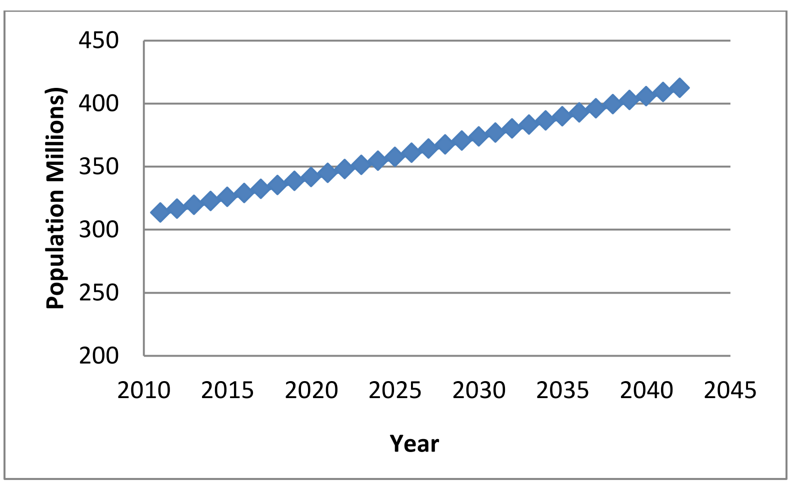
Figure 2 illustrates the expected growth in U.S. per capita income. From a base of $42,800 in 2011, per capita income is expected to increase 170 percent to $115,600 by 2042.



Source: Based on data from IHS Global Insight 2012

Figure 2: U.S. Per Capita Income Forecast 2011-2042

The U.S. population is expected to increase 32 percent from 313.4 million people in 2011 to 412.2 million in 2042, as shown in Figure 3.[6]

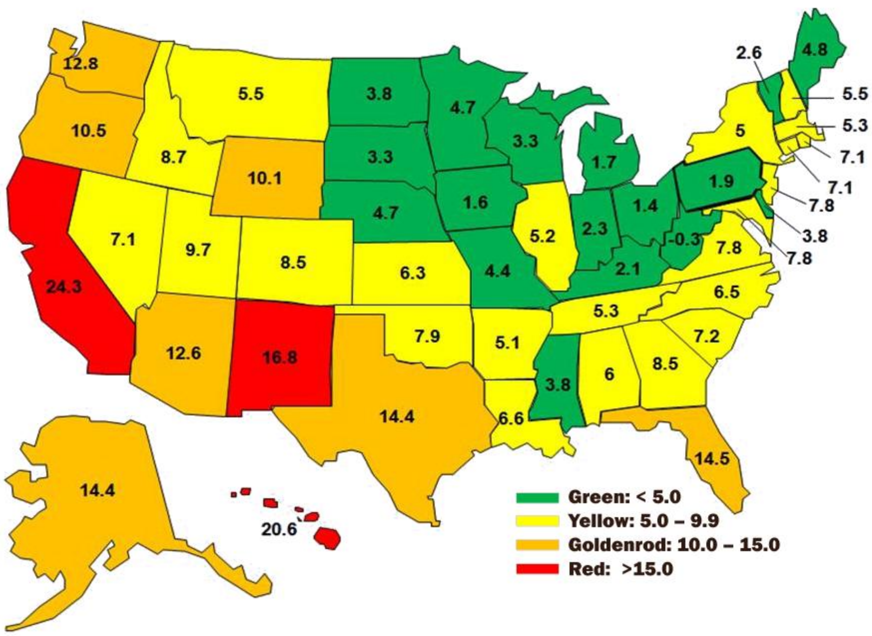


Source: Based on data from IHS Global Insight 2012

Figure 3: U.S. Population Forecast 2011-2042

[6] The U.S. Economy, The 30-Year Focus. 2012. IHS Global Insight, First Quarter 2012.

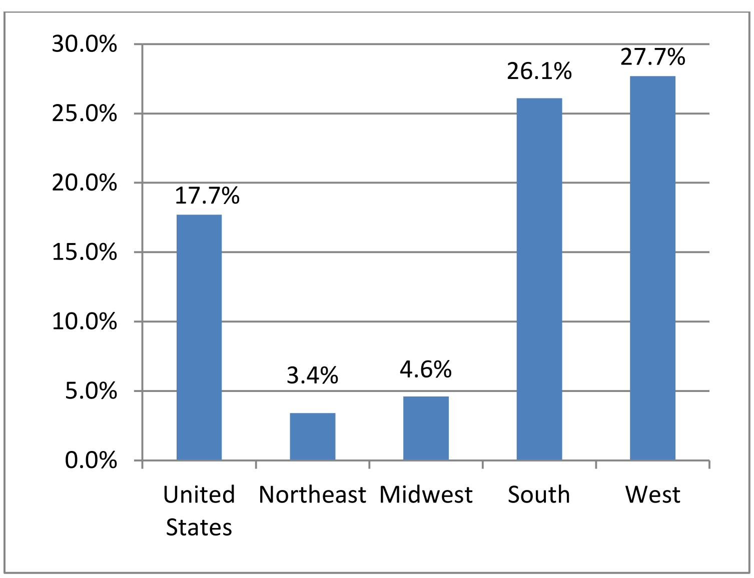
However, this growth in the U.S. is not expected to be evenly distributed geographically. It is predicted that the prevailing trend of population shifts to warmer, urban areas will continue over the next several decades. The growth in demand for transportation infrastructure and services will be greatest in those areas of the U.S. with the highest population growth.



Source: U.S. Census Bureau; Projections of the Total Population of States, 1995 to 2025

Figure 4: U.S. Population Growth by State 2015-2025

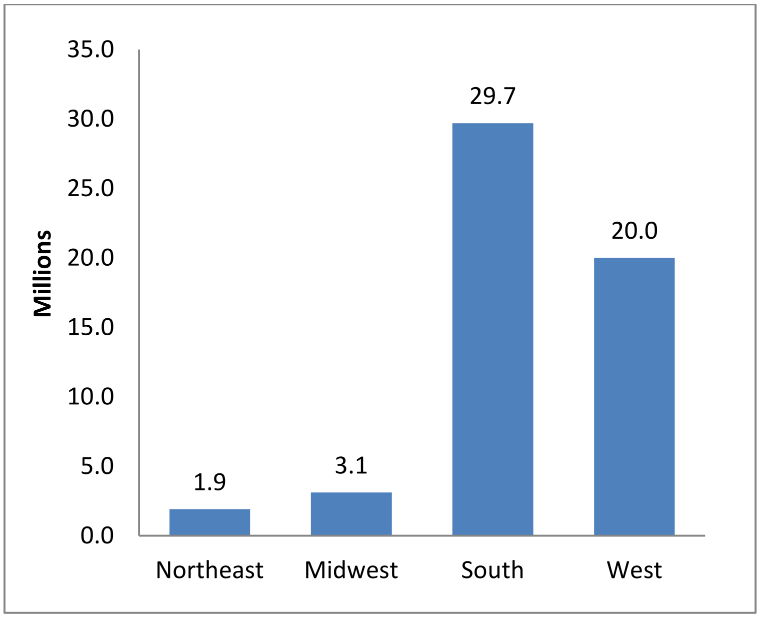
Figure 4 shows the percent population growth by state forecast by the U.S. Census Bureau between 2015 and 2025. Figure 5 shows percent growth projections by U.S. region and Figure 6 shows the forecast numerical change in population by region.



Source: U.S. Census Bureau, Population Division; 2005 Interim State Population Projections

Figure 5: Percent Change in Population by Region of U.S. 2010-2030

Each of these forecasts indicates greatest population growth in the West and South. Since change in demand for transportation services follows change in population, it follows that the largest growth in demand for future transportation services will be in the West and South.



Source: U.S. Census Bureau, Population Division; 2005 Interim State Population Projections

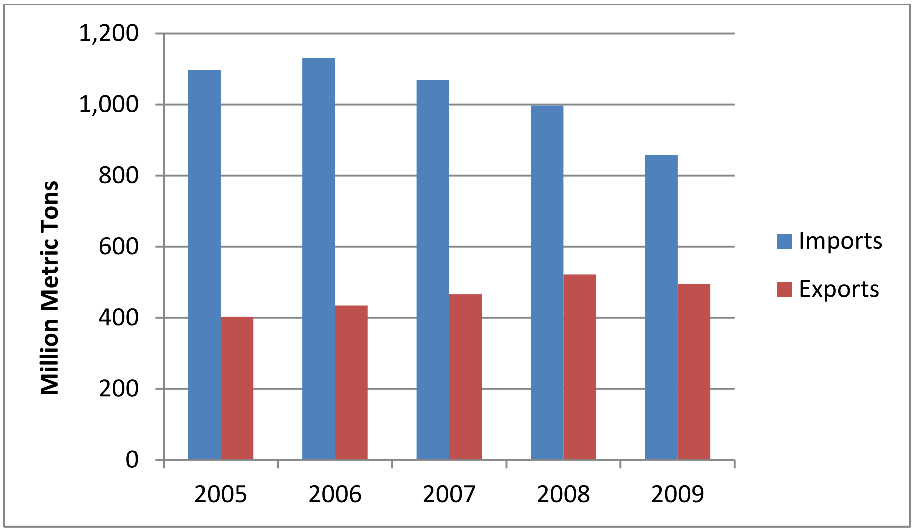
Figure 6: Change in Population by U.S. Region 2010-2030

U.S. Historical Commodities and Composition

U.S. Historical Trade

A look at historical U.S. trade adds perspective to the forecasts. In 2010 U.S. foreign water trade totaled 2.34 billion short tons[7]. Figure 7 shows the total U.S. imports and exports for a 5-year range. Petroleum products make up over half of all U.S. imports with respect to tonnage. Imports declined between 2006 and 2009 due to the U.S. economic recession. Exports increased between 2005 and 2008. Exports decreased slightly in 2009 reflecting the global economic downturn.

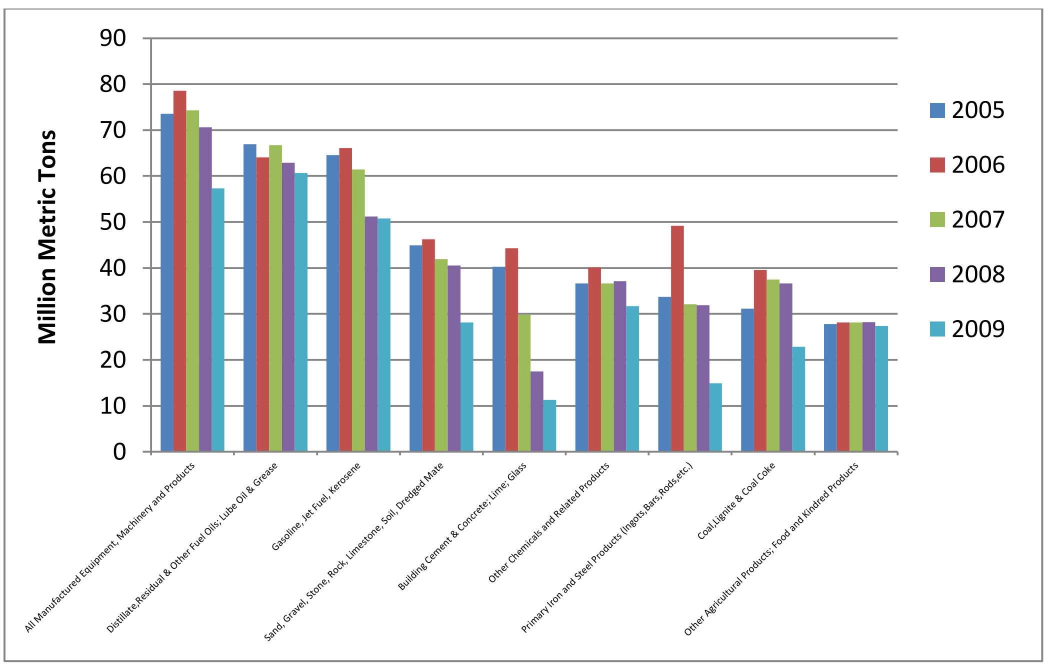
[77] Waterborne Commerce Statistics Center, Transportation Facts and Information, 2011.



Source: USACE Institute for Water Resources, Waterborne Commerce Statistics Center

Figure 7: Total U.S. Imports and Exports, Historical

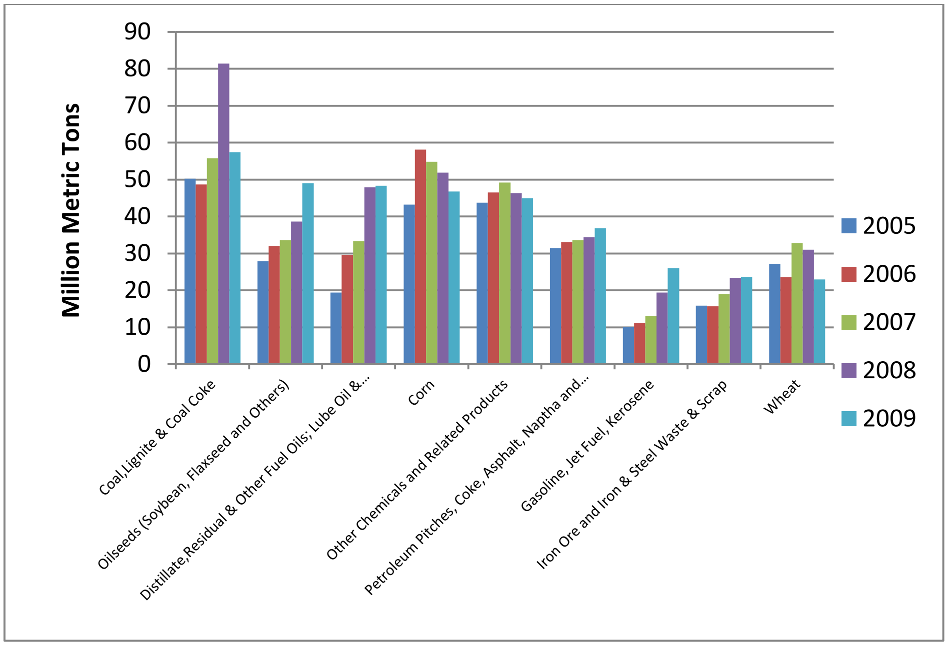
It is clear that while exports grew over the five-year period, imports appear to have been impacted by a series of events in the U.S. and abroad. Significantly impacted were commodities such as building cement, iron and steel, which have decreased more than 50 percent from their peak of the housing boom in 2006. Figure 8 shows U.S. imports by commodity type for the years 2005-2009.



Source: USACE Institute for Water Resources, Waterborne Commerce Statistics Center

Figure 8: U.S. Imports by Commodity Type 2005-2009

Figure 9 illustrates selected U.S. exports for the years 2005-2009 by commodity type. These exports represented the largest exports by volume based on 2009 tonnages. As shown, exports were dominated by coal products in 2009. While imports were clearly impacted by recessionary pressures, exports were affected less so. As a whole exports increased 23 percent from 2005 through 2009.

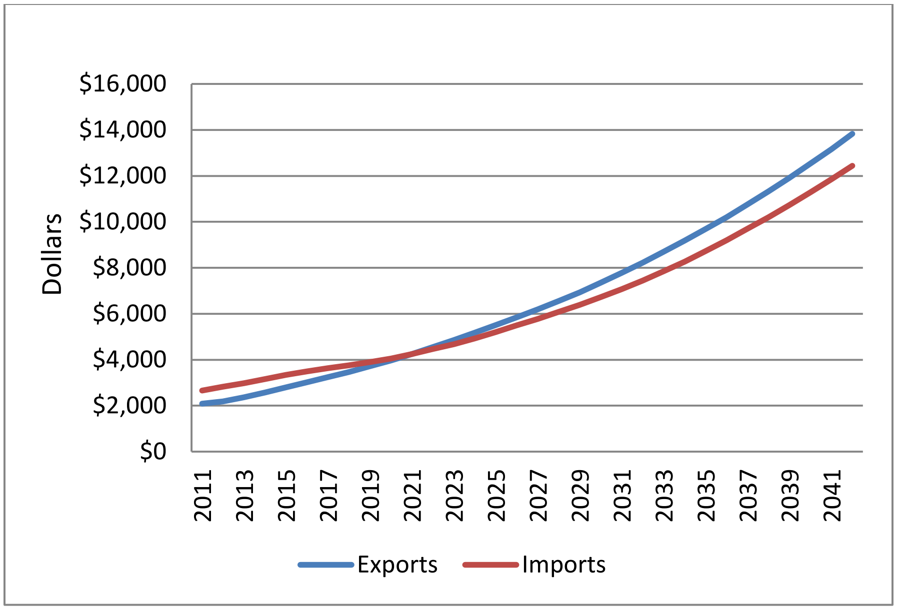


Source: USACE Institute for Water Resources, Waterborne Commerce Statistics Center

Figure 9: Selected U.S. Exports by Commodity Type 2005-2009

Trade Forecast

IHS Global Insight (IHS-GI) has forecast U.S. imports and exports through 2042. Imports are expected to grow from $2,666 billion in 2011 to $12,444 billion in 2042. Exports are projected to increase from $2,088 billion to $14,831 billion over the same time period. Exports are forecast to exceed imports beginning in 2022 (Figure 10).

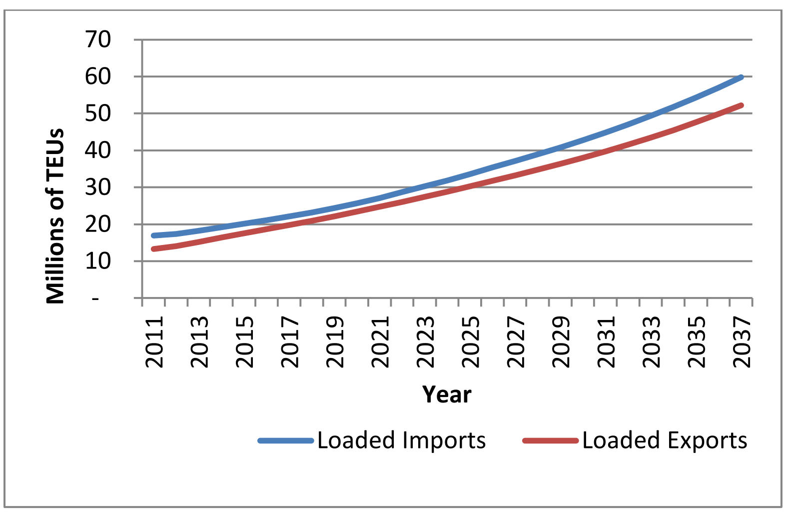


Source: IHS Global Insight, The U.S. Economy, The 30-Year Focus, First Quarter 2012

Figure 10: Forecast of U.S. Trade 2011-2042

Forecast and Containerized Cargo

IHS-GI forecasts for bulk and containerized trade is presented in Figure 11. Figure 12 indicates TEU imports increasing from about 17 million to 60 million from 2011 to 2037.[8] Exports are shown to increase from 13 million to 52 million containers over the same time period.



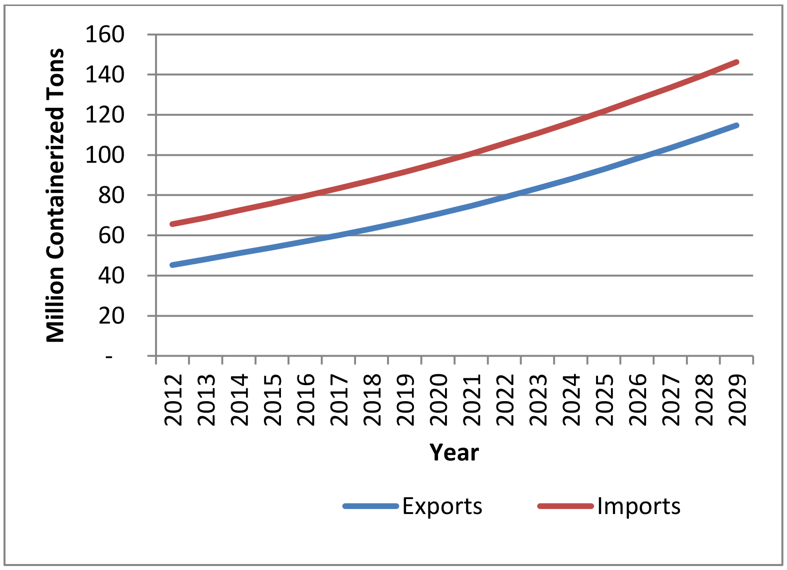
Source: IHS Global Insight

Figure 11: U.S. Forecast Import and Export TEUs 2011-2037

[8] TEU or **twenty-foot equivalent unit** is an inexact unit of cargo capacity often used to describe the capacity of container ships and container terminals. Actual containers vary in length from 20 to 53 feet.

Regional Breakdowns

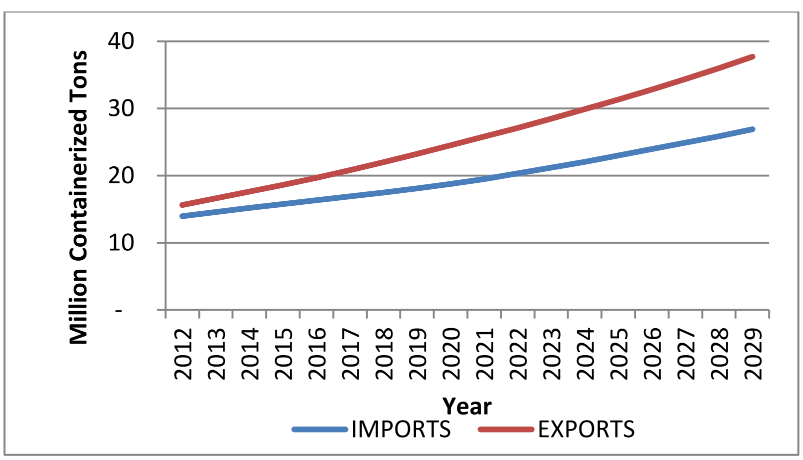
Several regional forecasts were available to this study. Two from IHS-GI represented the East and Gulf Coast forecast of containerized tons. One from the Tioga Group focused on San Pedro Bay. One from MSI forecast total East Coast TEU traffic. Figure 12 shows containerized tons on the East and Gulf Coasts through 2029. On the East Coast, import and export tonnage is expected to grow from 65.66 million tons to 146.3 million tons, an increase of 123 percent by 2029.



Source: IHS Global Insight

Figure 12: East Coast Containerized Imports and Exports 2012-2029

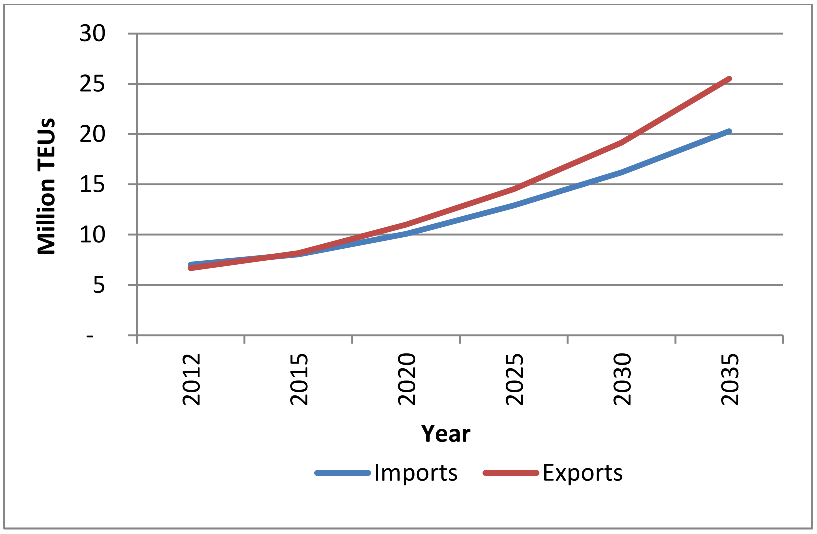
Figure 13 illustrates that Gulf Coast containerized tonnage is expected to grow from 29.6 million tons to 64.6 million tons, an increase of 118 percent by 2029.



Source: IHS Global Insight

Figure 13: Gulf Coast Containerized Imports and Exports 2012-2029

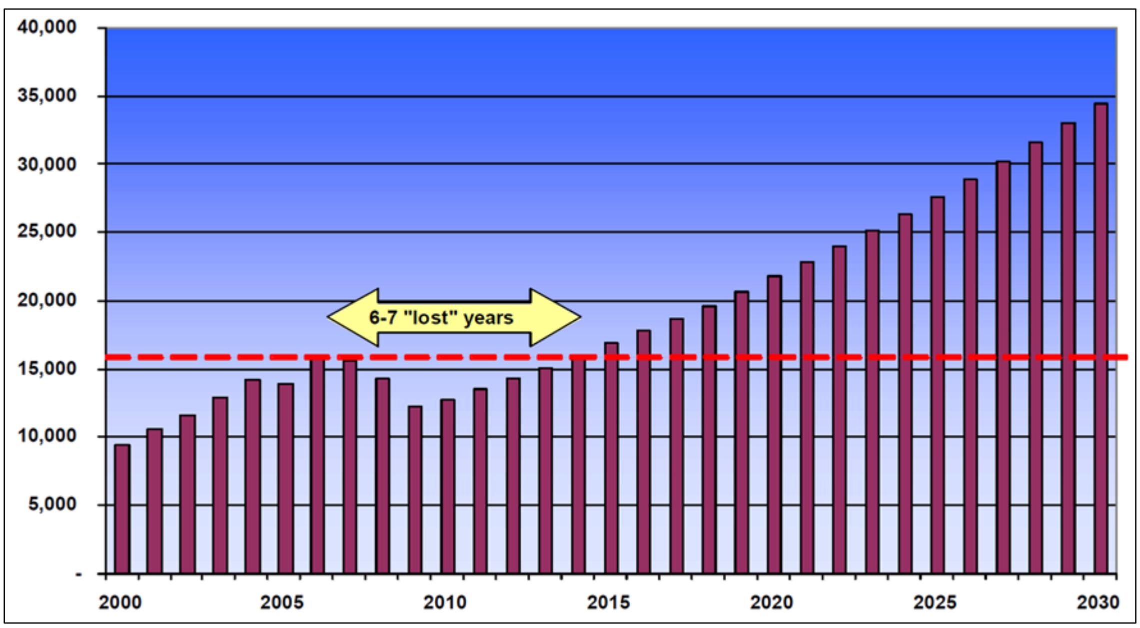
The MSI TEU forecast from 2010 to 2035 is shown in Figure 14. Movements of TEUs through East Coast ports are expected to triple from the current 15 million TEUs to about 45 million TEUs in 2035.



Source: MSI

Figure 14: East Coast Forecast TEUs 2012-2035

A forecast for San Pedro Bay TEU traffic, which is representative of West Coast trends, was obtained from the Tioga Group (Figure 15). This forecast was completed prior to the economic downturn of 2008 and then subsequently updated. The adjusted forecast shows traffic rebounding to historical levels by 2013 and projects growth to 36.7 million TEUs by 2030.



Source: Tioga Group; San Pedro Bay Container Forecast Update

Figure 15: San Pedro Bay TEU Forecast 2010-2030

Maritime Transportation Technology

Transportation Infrastructure and Global Trade

Global trade is encouraged by trade policies that act to remove barriers and protections for domestic producers. Seaborne trade linking continental land masses (e.g., Asia and North America) benefits from continuing advances in oceangoing vessel efficiencies and supporting infrastructure.

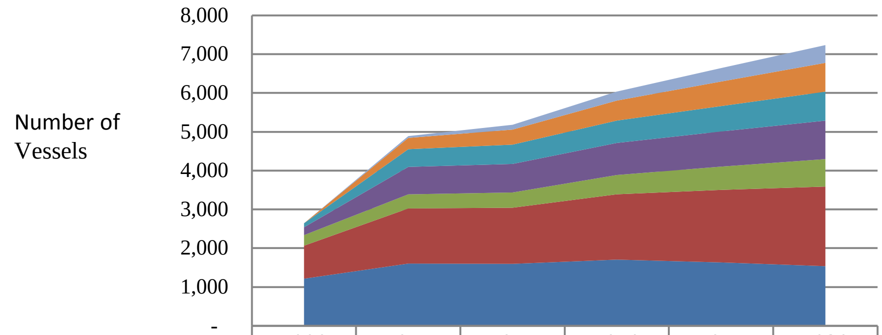
In the U.S., this infrastructure includes port facilities, port channels, ocean-route canals and connecting channels, highway and rail connections to ports, and overland and waterway feeder systems and line routes. Any inefficiencies in this transportation system act as a damper on U.S. exporters' abilities to realize the full potential of the export market and the vessels engaged in that trade.

World Vessel Fleet

The composition of today's world vessel fleet and what portion of that fleet calls at U.S. East, West and Gulf Coast ports is a basis for understanding how the fleet is changing and the ramifications that changes in fleet composition could have on U.S. ports. Vessels can be characterized by type and size. Shippers and carriers are using larger ships in global trade to gain transportation efficiencies and cost savings, which have enormous importance in this very competitive market. The larger containerships, tankers and bulk commodity vessels are currently in excess of 1,000 feet long, more than 125 feet wide and can draw in excess of 50 feet of water. The world vessel fleet is not static. Every year new ships are built and added to the fleet.

Containerships

Containerships are cargo ships that carry their load in containers measured in Twenty-Foot Equivalent Unit (TEU) "boxes." Since the inception of containerized cargo in the 1950s, the container shipping industry has continued to evolve toward greater efficiency. Greater efficiency means moving more loaded boxes per voyage, which in turn creates incentives to build even larger vessels. However, there are constraints to increased vessel sizes. Perhaps the most obvious constraint is the size of the Panama Canal, which is currently undergoing an expansion. *Post-Panamax* vessels exceed 5,200 TEU.



	2000	2011	2015	2020	2025	2030
12 k TEU +	-	47	124	232	348	458
7.6 k to 12 k TEU	-	291	388	515	632	742
5.2 k to 7.6 k TEU	104	456	498	577	654	747
3.9 k to 5.2 k TEU	203	707	735	826	905	991
2.9 k to 3.9 k TEU	272	364	393	497	600	708
1.3 k to 2.9 k TEU	850	1,420	1,446	1,684	1,869	2,051
0.1 k to 1.3k TEU	1,214	1,604	1,596	1,706	1,633	1,537

Source: MSI

Figure 16: Historical and Forecast Fully Cellular Container by TEU Band 2000-2030

According to the *Journal of Commerce*, half of containerships on order exceed 10,000 TEU capacities. Vessels of 10,000 TEUs and over accounted for 48 percent of the order book as of October 2011. It is evident that large ships are displacing smaller ships in all trade routes due to cost efficiencies of larger ships, which leads to a growth in average container vessel size over time. In 2000, the average container vessel size was 2,900 TEUs. In 2012, the average vessel size has grown to 6,100 TEUs. Figure 16 depicts this increase in size and number of larger vessels that make up the world fleet.

While the number of *post-Panamax* vessels projected for 2030 is only 30 percent of total vessels, Table 1 demonstrates they will represent 62 percent of the total TEU capacity of the container vessel fleet at that time.

Table 1: Unconstrained Forecast of TEU Capacity as a Percent of Total by TEU Band 2012-2030

Vessel Size	2012	2015	2020	2025	2030
0.1 k TEU to 1.3k TEU	8%	6%	6%	5%	4%
1.3 k to 2.9 k TEU	18%	15%	14%	13%	12%
c 2.9 k to 3.9 k TEU	7%	6%	6%	7%	7%
d 3.9 k to 5.2 k TEU	21%	19%	17%	15%	14%
e 5.2 k to 7.6 k TEU	19%	18%	17%	16%	15%
f 7.6 k to 12 k TEU	17%	20%	20%	21%	21%
g 12 k TEU +	9%	15%	20%	24%	26%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

Note: post-Panamax vessel bands shaded in gray
Source: MSI

Bulk Carriers

A bulk carrier is specially designed to transport unpackaged bulk cargo such as grains, coal, ore and cement. The current trend is to "light load" bulk vessels at New Orleans for vessels that serve export markets via the Panama Canal. These vessels do not currently fill to their full capacity due to draft restrictions at the Panama Canal. For vessels with a 45 foot design draft, which currently light load to 39.5 feet, transportation cost savings have been estimated to be $0.04 per bushel of grain for foreign flag vessels.[9] It is expected that these vessels would be able to fully load after the Panama Canal expansion. "Small" *Capesize* vessels (80,000+ Dead Weight Tons (DWT)) will be able to fit through the expanded canal. They will be capable of redeployment to serve the U.S. export market.

Like containerships, bulk carriers on order are also trending to larger sizes. Ship designers are working on new *Panamax* vessel designs to maximize the capacity and efficiency of the expanded canal. Table 2 shows the world bulk vessel fleet and the order book in 2010. Capacity growth is greatest in the *post-Panamax*, *Capesize* and *Very Large Ore Carryer* (VLOC) vessel classes. The *post-Panamax* fleet is expected to increase by 153 percent, the *Capesize* vessel class by 83 percent and the VLOC by 109.8 percent.

[9] USACE Institute for Water Resources

Table 2: Bulk Vessel Fleet and Order Book – 2010

Type of Vessel	Size (dwt)	Current Fleet		On Order		% Change of Fleet Capacity
		No. of Vessels	Capacity (mdwt)	No. of Vessels	Capacity (mdwt)	
Handysize	10,000-40,000	2,636	72.0	793	25.9	35.4%
Handymax	40,000-60,000	1,801	89.2	884	50.4	55.9%
Panamax	60,000-80,000	1,408	101.1	273	20.3	20.2%
Post-Panamax	80,000-110,000	311	27.7	461	40.5	153.0%
Capesize	110,000-200,000	793	131.0	625	107.0	83.0%
VLOC	200,000+	172	41.4	151	43.8	109.8%
Total		7,121	462.4	3,187.0	287.9	62.7%

Note: million deadweight tons (mdwt)

Source: U.S. Department of Agriculture and U.S. Department of Transportation; Study of Rural Transportation Issues. April 2010

The Panama Canal expansion offers an example of the effect that larger vessels and lower ocean rates can have on shipper opportunities. Informa Economics, Inc. estimates that the larger, more efficient *Cape* class ships reduce the cost of the movement of grains to northeast Asia by an all-water Panama Canal route by $0.31 to $0.35 per bushel of grain.[10] Delay times through the Canal will also be reduced – an additional benefit for bulk commodities that could not justify paying fees for reserving slots in the current canal. In fact, any infrastructure improvement that allows ports to take advantage of the larger global fleet enhances the competitive position of that port relative to other ports, and vessel efficiencies can be expected to have the same impact on other dry bulk commodity rates. This is significant to coal producers, the other dry bulk commodity exported in volume by the U.S.

Panama Canal Expansion

The Panama Canal is set to double its cargo throughput capacity when it completes expansion plans in 2014. The new locks will move vessels large enough to carry three times the volume of what can move through the canal today, although the existing locks will remain *Panamax* limited. More efficient and larger vessels passing though the canal are expected to impact markets, although these impacts will depend on the structure and level of the Panama Canal fees and a variety of other factors. If there is a significant reduction in the cost of the water route as a result of going through the canal, some freight traffic may shift from calling at West Coast ports to calling at East Coast ports. Figure 17 shows the change in lock size of the Panama Canal expansion. Figure 18 shows a selected Asia to U.S. East Coast service route.

If ships transiting the Panama Canal are too large to call at East Coast or Gulf Coast ports, a transshipment service in the Caribbean or at a large East or Gulf Coast port may develop. A transshipment service allows the largest vessels to unload containers at the transshipment hub for reloading on smaller feeder vessels for delivery to ports with less channel capacity. These ideas are more fully explored in chapter 3.

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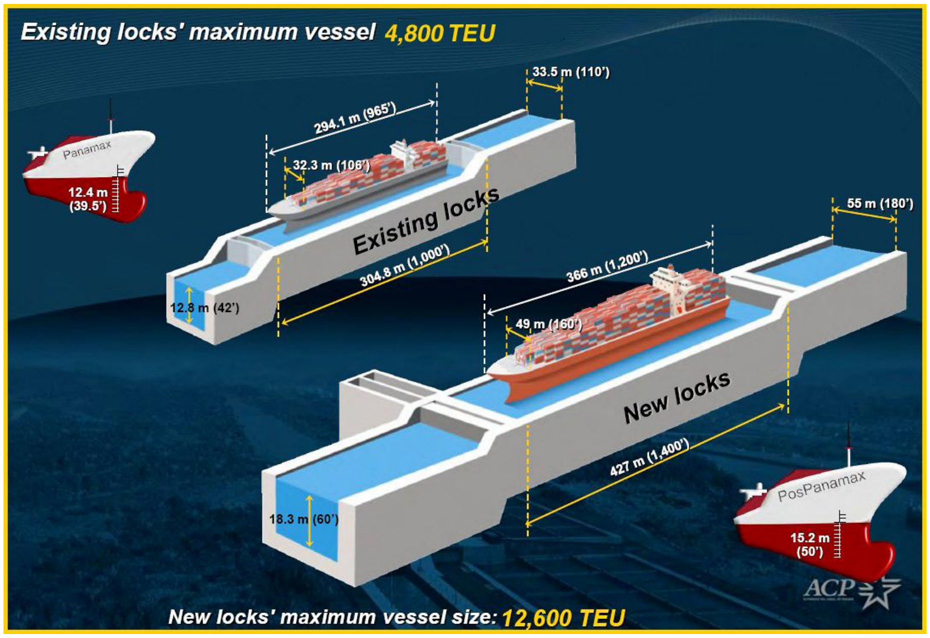
[10] Panama Canal Expansion: Impact on U.S. Agriculture, Informa Economics, September 2011.
Note: This estimate of transportation cost savings assumes a Cape class vessel.

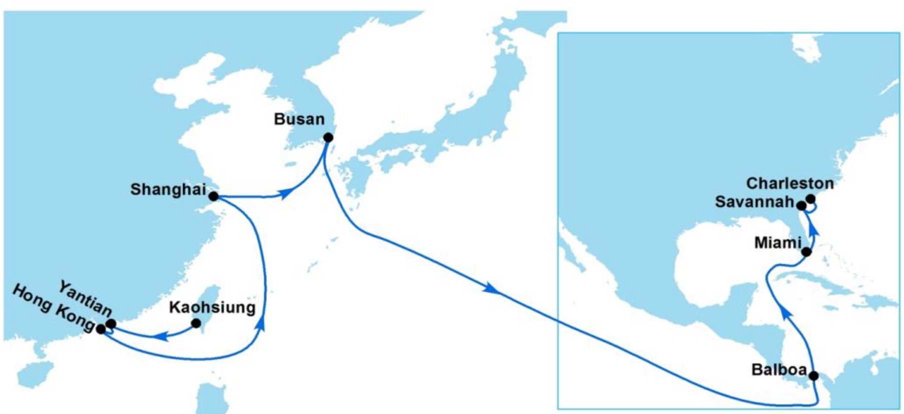
Vessels Transiting the Panama Canal 40% Longer, 64% Wider and 50 Ft Draft



Source: Panama Canal Authority, February 2011

Figure 17: Panama Canal Dimensions

Larger Vessels from the Pacific Rim Can Travel Directly to the Atlantic Coast



Source: A.P Moeller Maersk Group, 2011 Service Schedule

Figure 18: Routes from Pacific Rim to Atlantic Coast

The ability to employ larger bulk vessels could potentially lower the delivery cost of U.S. agricultural exports to Asia. This is not likely to have a significant impact on the mix or quantity of total U.S. agricultural or other commodities exported, but could have a significant impact on the mix or quantity of U.S. agricultural or other commodities moving down the Mississippi River for export at New Orleans.

However, there is uncertainty concerning the extent to which the Panama Canal expansion and the growth in average vessel size will impact trade and trade routes, but the industry is preparing for expected changes. West Coast ports and their rail partners are investing heavily now to increase the capacity and efficiency of the intermodal land bridge to ensure it remains competitive and keeps market share. While the possibility of building transshipment hubs at some ports is being explored, their use may add time and cost that may exceed the benefits of using larger vessels. The Panama Canal Authority may set its fee structure to capture the majority of transportation cost savings, which would limit the cost savings experienced by the shipper or carrier, the producer or the consumer. What seems certain is that some mix of these impacts will be realized gradually over time as market participants gain better certainty of the options they face.

Panama Canal Expansion Impacts on Vessel Fleets

There are mixed opinions regarding what kind of changes the Panama Canal expansion will bring to the fleet mix calling at U.S. ports and the routes that they follow. Shipper responses to change are affected by delivery time, reliability, capacity limits on alternative routes and volume. These variables can be linked to port facilities. Port facilities differ regionally regarding channel depths, crane capabilities and landside intermodal operations. Gulf and East Coast ports mainly distribute containers by truck, whereas West Coast distribution occurs mainly by rail. Many of the West Coast ports already provide adequate water depths to accommodate large vessels.

Experts in the shipping industry expect that once the Panama Canal expansion is complete in 2014, deployment from Asia to the East Coast will begin to closely resemble the fleet mix calling at the West Coast. IHS-GI has forecast the container fleet expected to call at East Coast ports. Table 3 shows the number of ships expected to be deployed on East Coast services through 2035. According to the forecast, in 2012, *post-Panamax* vessels are limited to trans-Atlantic trade. In 2015, with the expansion of the Panama Canal, the transition to *post-Panamax* vessels will include Asian origins. *Post-Panamax* vessels will dominate the East Coast fleet by 2020. This forecast assumes the East Coast ports have the capacity to accommodate the *post-Panamax* fleet. The actual number of vessels deployed to the East Coast and how efficiently these vessels are utilized will depend on the ports' future capacities, including channel depth and width, turning basin size, dock length and crane size.

Table 3: Forecast East Coast Container Fleet 2012-2035

	2012	2015	2020	2025	2030	2035
0.1 - 1.3 k TEU	24	11				
1.3 - 2.9 k TEU	34	12	6	4	3	3
2.9 - 3.9 k TEU	28	12	10	4	4	2
3.9 - 5.2 k TEU	140	95	78	58	42	29
5.2 - 7.6 k TEU	86	114	153	156	159	168
7.6 - 12.0 k TEU	26	61	96	155	227	322
12.0 k TEU +		3	13	42	82	136

Note: *post-Panamax* vessel bands shaded in gray

Source: MSI

Summary

Despite the recent worldwide recession, world trade is expected to increase along with population and income growth, as it has for the last 100-years. The world vessel fleet is projected to increase both in number and vessel size. The larger vessels have already begun to call at U.S. ports and will increase in number and size over time. This trend will be accentuated by the expansion of the Panama Canal.

Chapter 2: Current Capacity

Multi-Modal Transportation System

The U.S. multi-modal freight transportation system is comprised of deep-water ports, inland waterways, railways and highways. They all play a role in the movement of goods domestically and internationally.

Inland waterways, such as the Mississippi, Columbia-Snake and Ohio River systems, have the highest impact on grains, oilseeds and coal exports. Alternatively, northeast Asia is the largest export trading partner for West Coast ports.

Ocean transportation overland rail rates determine the geographic break point between making the haul by rail from the Midwest to the West Coast versus a barge haul to New Orleans along the Mississippi River System to make the lengthy ocean voyage to Northeast Asia. Oceangoing containership rates are generally stable due to negotiated rates. Bulk carrier rates are more susceptible to swings in demand, like the sudden rise caused by the growing Chinese demand for ores, coal and grain.

In recent years, *post-Panamax* vessels have started to call at U.S. ports. It is believed that the Panama Canal expansion will increase the opportunities for trade as it will enable carriers to deploy larger, *post-Panamax* vessels to its Asia-East Coast and Asia-Gulf services ports. Previously large vessel class trade with Asian markets occurred mainly at West Coast ports.

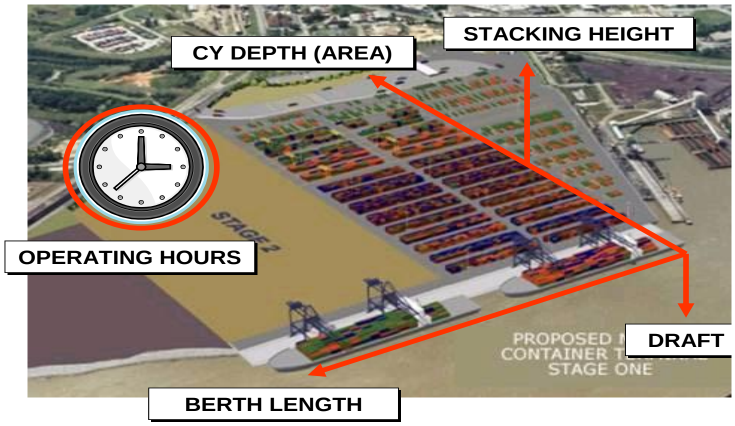
"Multi-modal" vs. "Intermodal"

Multi-modal refers to a multi-faceted transportation system, such as the one in the U.S. that encompasses deep-water ports, inland waterways, railways and highways in which freight carriers typically ship using at least two different methods of transportation but are financially liable for the cargo from start to finish.

Intermodal, on the other hand, refers to the ability to move containerized cargoes relatively seamlessly using a multi-modal transportation system; for example, moving goods in the same container from a ship to a truck or rail car.

U.S. Port Capacities

The capacity of a port broadly describes a port's ability to accommodate large volumes of cargo as well a wide variety of vessel sizes. A port's ability to handle influxes of cargo that accompany "just in time" delivery practices is critical. If, for example, a port were to approach its capacities and be unable to accommodate additional vessels or cargo, shippers may choose a different service route for their cargo.



Source: Tioga Group

Figure 19: Elements of Port Capacity

> "Just in time" delivery practices are planned to reduce the amount of time a ship is idle, thereby reducing transportation costs.

Many factors contribute to a port's ultimate capacity. Channel depth is important as it can indicate the maximum allowable sailing draft for a particular vessel (or the maximum vessel size) that could call at the port. Intermodal access, terminal space, stacking height rules, operating hours and productivity all play critical roles in moving cargo effectively and efficiently. There is little benefit to providing deeper channels if terminals do not have capacity to accommodate larger vessels. Likewise, if channels become a bottleneck, there is little benefit to expanding terminals unless channels will be improved. Therefore, a comprehensive look at both landside and waterside capacity is required.

Port Utilization

Since the advent of containerized cargo in 1956, U.S. ports have been seeking ways to accommodate larger vessels as well as provide space for an anticipated increase in containers. Physical limitations such as channel depth, storage yard space, berthing facilities, and landside productivity (i.e., container turnover rates) determine how much throughput a port can potentially handle in a given year. IWR is studying the near-term throughput capacities for a number of marine container terminals located in the U.S., several Canadian ports, a Mexican port and a potential "transshipment" port.[11]

That study will address the following questions:

- What are the near-term and long-term capacities of the major container ports in the U.S.?
- What factors constrain the capacities of these ports?
- How well is capacity currently utilized?
- How well are the major ports prepared to handle larger vessels?
- How do the smaller container ports or terminals fit into the picture?

[11] U.S. Army Corps of Engineers, Institute for Water Resources. *IWR Container Ports Capacity Report 2012 (draft).*

The preliminary conclusions of that draft study are that ports on the East and Gulf Coasts have sufficient used and unused physical capacity in the near term, particularly in the South Atlantic. The West Coast ports are closer to capacity than the East and Gulf Coast ports. Many industry observers interpreted the 2004 peak season congestion as a sign that the ports of Los Angeles and Long Beach were reaching capacity. However, that 2004 peak season congestion was followed by little or no congestion in subsequent years, in spite of increased cargo volumes; container yard capacity appears to be the most constrained.

Table 4 describes capacity metrics for major U.S. ports.[12] Values close to 100 percent would indicate a port is operating at or near capacity; low percentages often indicate capacity for growth.

- ***Container Yard/Gross Ratio*** reflects the proportion of the entire terminal that is dedicated to containers. Many U.S. ports have relatively low densities when compared with Asian and European counterparts. Asian and European terminals, however, typically devote almost all their terminal space to container yard (CY) functions and rarely have on-dock rail, chassis storage, warehousing, or other functions in the terminal acreage. As a result, Asian and European ports show much higher throughput per acre than in the U.S.

- ***Container Yard Utilization*** measures the productivity of the space dedicated to containers. It is often a function of the operating hours, crane speed and density of cargo. The figures range from a low of 14 percent in Mobile to 83 percent in the Port of Virginia.

- ***Crane Utilization*** in terms of annual TEU is relatively low, averaging 34 percent for the U.S. as a whole. This relatively low utilization might imply an excess of crane capacity. The primary purpose of crane capacity is to turn vessels quickly. Whether there is one vessel per week or five, each vessel will need two or more cranes. The terminals surveyed averaged two cranes per berth. Crane utilization is co-determined with berth and vessel utilization. A vessel is far more costly to own and operate than the cranes that serve it, so crane utilization is effectively sacrificed to vessel utilization.

- ***Berth Utilization*** is based on the number and lengths of berths as well as vessel calls. As most container vessels in service are less than 1,000 feet long and 1,000-foot berths are common, berth length *per se* has seldom been a limiting factor. That will eventually change as *post-Panamax* and *Super-post-Panamax* vessels become more common on the East and Gulf Coasts. As of 2010, the figures show significant potential for increased utilization. In practical terms, berths that are handling two vessels per week could probably handle four. This conclusion, however, depends on vessel size and the total cargo discharged and loaded. The average vessel capacities are low compared to the maximum vessel sizes that ports say that they can accommodate with the available

[12] IBID

draft. Ports typically receive few if any calls from the maximum size vessels, so most calls are made by a mix of smaller container ships.

- **Throughput** could be increased by using larger vessels for the same number of calls, making more calls with the same vessels, discharging and loading more of the vessel capacity at each call, or any combination of these changes. In each case, more container cranes and/or crane time would be required to handle the increased cargo while keeping the vessel on schedule. The crane capacity estimates are based on availability for two shifts per day, 250 days per year (4,000 annual hours). The cranes are, in fact, generally available 24 hours per day if the terminal operator needs the additional shifts to turn the vessel on schedule and is willing to pay for overtime.

The capacity and utilization measures presented in table 4 provide insights into the performance of U.S. container ports and the challenges they face in accommodating the nation's growing trade.

The container yard (CY) is the operating heart of the marine container terminal, the area where containers are held, sorted, and transferred between vessel arrivals and departures. On average, about 50 percent of the gross terminal space at U.S. terminals is devoted to CY operations. The average is lower at ports with extensive on-dock rail terminals, consolidation facilities, and other operations within the terminal boundaries.

Container yard utilization reflects the ability of the terminal to accommodate growth with existing handling methods. Industry rules of thumb suggest that about 80 percent utilization is a practical upper limit beyond which periodic congestion becomes likely. Ports and terminals approaching this limit, such as NYNJ at 75 percent, New Orleans at 82 percent, or LALB at 75 percent, can accommodate growth by expanding or shifting to more land-intensive operating systems.

Utilization of shore side container cranes is typically low, averaging 34 percent across U.S. ports. Cranes are usually used for one daily shift, with additional shifts used to accommodate tight vessel schedules. Crane utilization is secondary to the utilization and rescheduling of the far more costly container ships, so ports and terminals will usually have enough cranes to handle peak demand. Crane utilization may be particularly low at ports such as Mobiles and Virginia which have recently added new terminals and cranes to accommodate future growth.

The average size of vessels actually calling at the ports is usually much smaller than the maximum that could be accommodated. The ratio is highest for ports such as Philadelphia (Delaware River), Savannah, Jacksonville, Houston, and Portland with shallow drafts. The table likewise shows that a vessel does not typically discharge and load its full capacity at each port. The highest average is at LA/LB, where an average vessel discharges and loads 56% of its capacity (equivalent to discharging 28% and loading 28%). Most ports share vessel calls with multiple U.S. and foreign ports, with the average discharge/load ratio correspondingly lower.

Table 4 provides three measures of berth utilization. The first focuses on the number of vessel calls. On average, U.S. ports receive about 29 percent of the maximum number of vessel calls that could be accommodated. The average is higher at smaller ports, and at ports handling multiple trade routes and steamship lines. Where the average approaches 80 percent, such as at Savannah or New Orleans, there may be a need to extend berths. Berth utilization with average vessels measures the extent to which port volume can grow using the current vessel mix and discharge/load ratio. In several cases U.S. ports are approaching this limit, and will need to start handling larger vessels to accommodate increased traffic. Berth utilization with the maximum vessel sizes is generally much lower, except at Savannah where the shallow draft has constrained the use of larger vessels.

The table provides the same measures for the two Canadian port complexes in British Columbia. These ports have substantial reserve capacity and the ability to handle very large vessels in competition with U.S. ports.

Table 4: 2010 Capacity & Utilization Measures

Container Yard	CY/Gross Ratio	CY Utilization	Crane Utilization	Berth Utilization - Vessel Call Basis	Avg. vs. Max. Vessel Capacity	Avg. Vessel Utl Discharge/Load	Berth Utilization - Avg. Vessel Basis	Berth Utilization - Max. Vessel Basis	Nominal Maximum Channel/Berth Draft (Feet)	Estimated Maximum Vessel TEU
North Atlantic Ports										
Boston	49%	31%	21%	35%	73%	38%	35%	25%	45'	5,183
NY/NJ	59%	75%	36%	43%	53%	55%	43%	23%	50'	7,470
Delaware River	29%	68%	29%	30%	65%	52%	40%	26%	40'	3,420
Baltimore	50%	23%	18%	18%	44%	71%	14%	6%	50'	7,470
VPA	42%	83%	30%	60%	54%	32%	77%	41%	49'	6,967
S. Atlantic Ports										
Charleston	43%	25%	35%	79%	61%	30%	89%	55%	47'	6,031
Savannah	41%	36%	45%	71%	101%	39%	89%	89%	42'	4,067
Jacksonville	33%	24%	17%	13%	69%	104%	13%	9%	37'	3,420
Port Everglades	85%	42%	49%	43%	56%	60%	57%	32%	39'	4,067
Miami	72%	53%	31%	40%	77%	66%	27%	20%	42'	4,067
Gulf Ports										
Mobile	58%	14%	12%	9%	114%	55%	9%	10%	42'	3,420
New Orleans	62%	45%	31%	57%	65%	31%	57%	31%	45'	5,183
Houston	63%	57%	37%	51%	92%	67%	46%	42%	40'	3,420
West Coast Ports										
LA/LB	55%	75%	43%	25%	37%	112%	25%	18%	50'	13,000
Oakland	57%	53%	29%	40%	65%	28%	40%	26%	50'	7,470
Portland	59%	26%	8%	15%	97%	47%	15%	14%	43'	4,419
Seattle	49%	64%	21%	40%	68%	36%	40%	27%	50'	7,470
Tacoma	56%	37%	15%	23%	53%	52%	23%	12%	51'	7,997
U.S. Mainland Ports	51%	51%	34%	39%	n/a	61%	30%	n/a	n/a	n/a
Canadian W. Coast Ports										
Prince Rupert	46%	76%	40%	50%	43%	36%	61%	26%	61'	15,048
Vancouver	56%	63%	52%	40%	40%	64%	46%	19%	51'	13,000

Source: USACE Institute for Water Resources

While some ports on the U.S. West Coast (LA/LB in particular) are closer to their capacity in percentage terms, the system as a whole could handle roughly double 2008 volumes before hitting CY or berth capacity constraints. However, that result would only be attained if the increased trade were distributed according to the available capacity – an unlikely outcome. A far more likely outcome is that some ports and terminals would see a disproportionate share of the cargo growth and hit capacity constraints in the long term while other ports and terminals remained underutilized.

Table 5 displays the reserve container capacity by region, which is a key indicator of the ability to handle increased traffic and cargo.

Table 5: Reserve Container Port Capacity by Coast

Metric	N. Atlantic Ports	S. Atlantic Ports	Gulf Ports	West Coast Ports
2010 TEU	8,239,000	6,687,000	2,409,000	18,960,000
Reserve CY Capacity-TEU	10,612,402	13,869,035	2,669,003	10,484,996
Reserve Crane Capacity – TEU	20,895,164	12,501,742	4,423,466	37,237,002
Reserve Berth Capacity – Vessel Calls	9,964	4,013	1,105	13,923
Reserve Berth Capacity – Avg. Vessel Basis	11,832,298	1,922,907	2,799,609	53,031,819

Source: USACE Institute for Water Resources

Secondary Ports

The map below (Figure 20) shows primary and secondary ports in the U.S. Primary ports often feature more dedicated container or bulk terminals. Secondary ports supplement the capacity of the major ports and handle trades and cargoes that do not fit in well with the large, dedicated container terminals. Secondary ports handle a mix of containerized, bulk and break-bulk shipments, so their container capacities are difficult to determine with precision. This mix of capabilities does, however, provide flexibility, particularly for project cargoes and other limited-duration needs. While these ports handle relatively small volumes of containers, several have specific importance to the imported fruit trade (e.g., bananas) and other niche markets. Some are part of larger complexes that include major military shipping points.

Source: USACE Institute for Water Resources

Figure 20: Primary and Secondary East and Gulf Coast Ports

Channel Depth Comparisons

An important capacity consideration is the vessel size a port can accommodate. Along with other factors, channel width and depth establish the maximum size vessel that can call at a port. West Coast ports such as Seattle, Oakland, Los Angeles and Long Beach all have 50-foot or greater channels. Northeastern ports such as Baltimore and New York[13] have or will soon have 50-foot channels. In the Southeast, Norfolk has 50 feet. Below Norfolk along the Southeast and Gulf Coasts there are no ports with 50-foot channel depths. However, Miami is scheduled to have a depth of 50 feet by 2014 and Charleston can already accommodate, at high tide, ships that require a depth of 50 feet. Figure 21 shows channel depths at selected ports around the country.

[13]The Bayonne Bridge presents and air draft restriction for the largest vessels calling at some of the container terminals in New Jersey and Staten Island. The Port Authority of NY/NJ is planning to raise the Bayonne Bridge and expects to complete that work in 2016.

Source: USACE Institute for Water Resources

Figure 21: Main Channel Depths at Selected Ports

Additional Capacity Factors

Other factors affecting port capacity include productivity, storage area, stacking height rules, operating hours and the capacity of surrounding highways, railroads, intermodal connectors to move containers to and from ports, and trained personnel to operate expanded terminals. Ports such as LA/LB have made tremendous strides in increasing productivity through measures such as facility upgrades and scheduling.

U.S. Port Capital Investment Plans

The Nation's ports are making significant investment of their own. The American Association of Port Authorities recently conducted a survey of their members regarding capital improvement plans. Table 6 shows planned investments over the next 12 years total over $21 billion.

Table 6: Preliminary results of AAPA U.S. port authority infrastructure spending survey - 2012-2016

Port's Projected Capital Expenditures 2012-2016	Projected Private Sector Capital Expenditures at ports 2012-2016	Port's Local Share of Security Expenditures Since 9-11	Port's % of Annual Budget for Security
$16,218,000,000	$21,418,000,000	$1,429,000,000	10.3% (average)

Source: American Association of Port Authorities

Summary of Primary and Secondary Port Capacity

There is little benefit to providing deeper channels if terminals do not have capacity to accommodate larger vessels. Overall, the North Atlantic, South Atlantic, Gulf and West Coast ports have substantial inherent capacity. They have adequate capacity in their birth, cranes and container yards to accommodate near-term growth. That growth can be achieved through more intensive use of existing terminals, cranes and berths. The existence of aggregate reserve capacity does not preclude slot shortages at ports and terminals that receive more than their share of growth.

Competition from Other North American Ports

IWR also examined the capacities for a number of ports outside the U.S. that can be viewed as competition to U.S. ports. When congestion reached a peak in Long Beach in 2004, for example, some cargo had been diverted to Lorenzo Cardenas and Manzanillo in Mexico.[14] U.S. West Coast ports have become understandably concerned about the diversion of traffic to Prince Rupert in British Columbia, which began operations in 2007.[15] It boasts an ice-free, 115-foot deep harbor and is about 1,000 nautical miles closer to Asian ports (two-days shipment time) than Southern California ports. The Canadian National Railway Company's rates from Prince Rupert to Chicago are approximately $300 per container lower than Burlington Northern Santa Fe Railway and Union Pacific intermodal rates to Chicago from Los Angeles. Canadian National Railway Company has also been investing heavily to widen tunnels, reinforce bridges and build sidings along the route from Prince Rupert to Chicago. (The steepest grade between Canada's Pacific Northwest and its Chicago end points is 1 percent in the Rockies). Prince Rupert is planning to quadruple its capacity to approximately 2 million TEUs with its Phase 2 Expansion project.[16]

Competition from South American Ports

China continues to propose investments in ports (a deepwater bulk port in Brazil) and overland infrastructure (a rail connector proposed for linking Colombian coal fields on the Atlantic side of the country to a Pacific port) in South America. These investments would improve the competitive position of Brazil as an ore and soybean exporter and Colombia as a coal exporter.

Transshipment Centers

The Port of Freeport, Bahamas has been viewed as a potential transshipment port, or hub, for cargo, similar to Singapore and other transshipment centers. The terminal is approximately 100 miles east of Miami, was opened in 1997 and is used primarily as a transshipment point serving the U.S. East Coast and global trade routes. It is able to handle large containerships given its

[14] Delays at U.S. Ports May Push Nippon, Maersk to Canada, Mexico, Bloomberg January 13, 2005.

[15] Remarks of Chairman Richard A. Lidinsky, Jr. Federal Maritime Commission at the Canada Maritime Conference Montreal, Canada September 21, 2011

[16] U.S. Army Corps of Engineers, Institute for Water Resources. *IWR Container Ports Capacity Report 2012 (draft).*

53-foot channel depth and proximity to Southeast ports. The 2012 Port Capacity Analysis indicates that Freeport has adequate capacity to handle future growth. Container Yard capacity appears to be its most constrained facility resource. However, the faster transshipment turnover it provides to carriers encourages future volume growth and improved berth capacity utilization.

Inland Waterways and Their Role in U.S. Export Trade

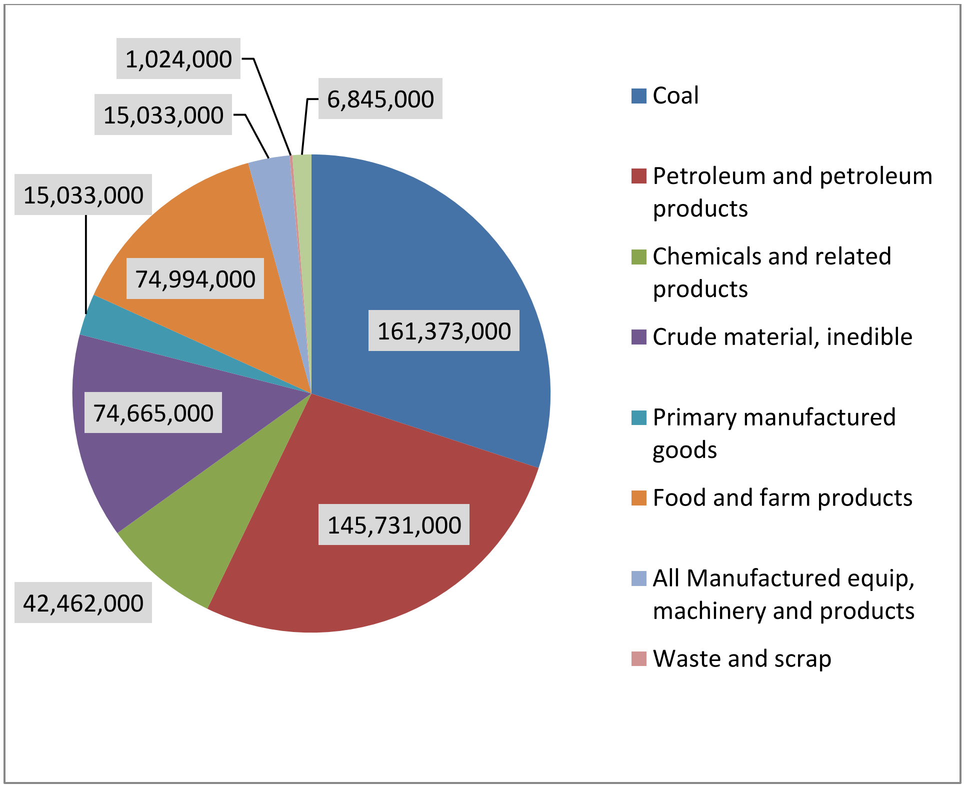
The inland waterways comprise rivers, waterways, canals, and the locks and dams that provide some 12,000 miles of commercially navigable waters. The flotillas of towboats and barges that operate on this system carry approximately 15 percent of the nation's domestic freight. Figure 22 shows how the inland waterways link the heartland of the U.S. to the coast.

Source: USACE Institute for Water Resources

Figure 22: The Inland Waterway Connection: Linking the Heartland to the Coasts

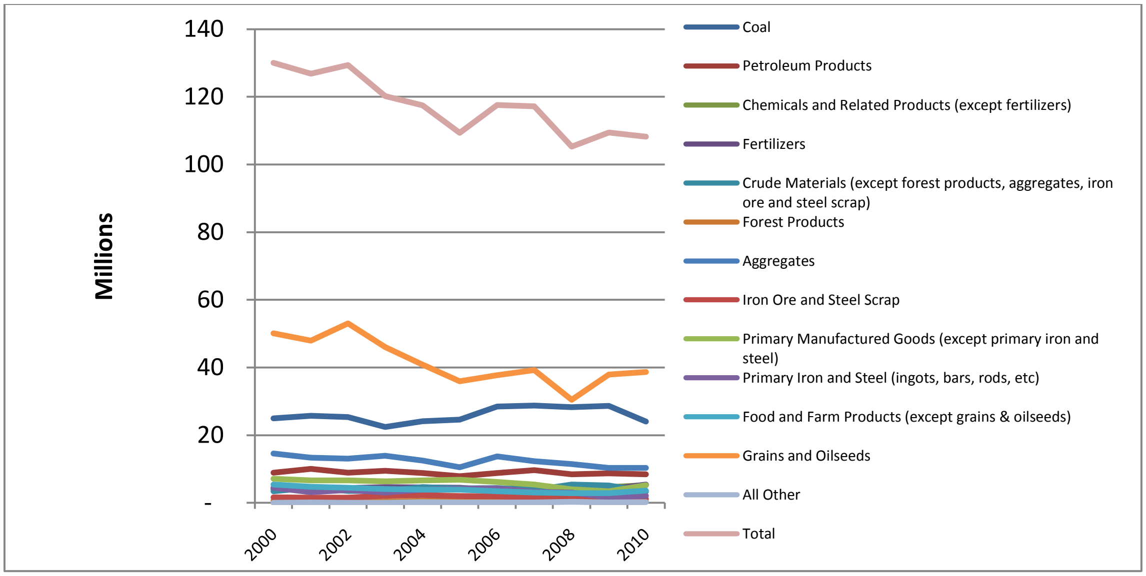
The biggest role of inland waterways in the export market has been in the global trade for grains and coal. U.S. producers of these commodities face stiff global competition. Investments in competing world ports are tapping production regions that were previously expensive to reach or nearly inaccessible. Examples include coal mines in Mongolia, deep water ports in Brazil for the export of soybeans, and rail lines from eastern coalfields in Colombia to the Pacific Ocean.

Shallow draft river systems handled 523 million short tons of cargo in 2009, while coastal systems handled an additional 168 million short tons. Including lake, intraport and intraterritorial movements, the system moved some 857 million short tons—actually a decrease in activity due to the severe recession during that year. The system typically handles more than a billion tons per year. The cargoes are mostly bulk commodities and raw materials such as coal (28% of the tonnage), petroleum (37%), grain and farm products (10%), chemicals (5%), aggregates, steel, and fertilizer (Figure 23). The Mississippi River System is the primary conduit for cargoes from the nation's Midwest grain belt to Gulf ports. Figure 24 shows traffic on the Mississippi has been declining over the last decade.



Source: USACE Institute for Water Resources, Waterborne Commerce Statistics Center

Figure 23: Total 2009 U.S. Internal Traffic by Commodity (short tons)



Source: USACE Institute for Water Resources, Waterborne Commerce Statistics Center, Waterborne Commerce Statistics

Figure 24: Tonnage (short tons) by Commodity Shipped on the Mississippi River 2000-2010

U.S. government export forecasts indicate near term growth in grain and coal exports that level off over the next 20 years[17]. These forecasts indicate that the U.S. will remain the single largest participant in the global grain trade, while U.S. coal producers will continue to hold a marginal position in the global market. Grain producer forecasts see most of their exports being shipped from the Center Gulf region around New Orleans, with about one-half of the increase in grain exports transiting the Panama Canal[18].

A Strong Intermodal System

The challenge will always be wise stewardship – maintenance and enhancements that anticipate future needs and uses. Foresighted planning, policy and investment are all required. The railroad industry responded to Staggers Act de-regulation in the 1980s by trimming capacity and becoming more efficient and more profitable. This return to profitability allowed railroads to invest heavily in main line expansion and terminal capacity; however, concerns persist over the railroads' ability to match demands. Public-private partnerships (like the Heartland Corridor Project (see Figure 31 on page 41) have already occurred and more partnerships of this nature may be required in the future.

A healthy trucking industry is vital to the freight transportation network, often accounting for the first and last leg of each freight shipment. These legs have become longer as railroads abandoned rural country elevators and coal load outs in favor of fewer and larger terminals capable of handling unit and shuttle trains. This has meant more miles travelled by trucks on rural roads, faster deterioration of roads and bridges, and more maintenance expense for public

[17] USDA 2011
[18] Panama Canal Expansion: Impact on U.S. Agriculture, Informa Economics, September 2011.

highway agencies. Repair work on the nation's highways and bridges was given a boost from American Reinvestment and Recovery Act funds, but experts suggest many more billions of dollars are required to bring the system up to safe and efficient standards.

Inland waterways in the U.S. are the most advanced and extensive in the world, greatly aiding in the economic development of vast expanses of interior North America and conferring benefits to U.S. consumers of electricity, agricultural products, construction materials, petroleum products and steel – nearly everyone. The inland waterways complement a web of highways and rail lines to form a national multi-modal freight transportation system – an engineering and logistical marvel built, redesigned, improved and expanded throughout the Nation's history. As a national freight network, it efficiently serves the largest and the smallest communities in the U.S. from coast to coast and allows goods produced far from ocean ports to reach and compete in global markets. Like any other piece of infrastructure, the freight network goes largely unnoticed until it becomes unreliable or is no longer there. The flexibility of the U.S. freight network has allowed each mode to cover for the other during service interruptions. Many segments of the freight community are concerned that this capability is largely played out just at a time when new opportunities are opening in the global market place.

U.S. Ports Served by Inland Waterways

Many of the major coastal ports in the U.S. are located on or connected to inland waterways. Ports served by inland waterways exported 346 million tons in 2010.[19] The Gulf Intracoastal Waterway (GIWW) and the Lower Mississippi River (including Lake Charles off the Calcasieu River) served ports that accounted for 72 percent of inland waterborne exports in 2010.

The Port of New York, NY and NJ and ports on or served by the Columbia-Snake, Great Lakes and Tennessee-Tombigbee-Black Warrior waterways account for most of the remaining share of exports from ports served by inland waterways. Ohio, Upper Mississippi, McClellan-Kerr-Arkansas (MKARNS), and Missouri river ports do not export directly, but reach the export market through ports on the Lower Mississippi River. Ports served by the GIWW – Houston, Corpus Christi, Texas City, Beaumont and others – are dominated by the petroleum and petrochemical trades; the Port of New York by containers; Great Lakes by ports; Mobile, the Lower Columbia River and the Lower Mississippi ports by dry bulk trades like coal, grains and ores, along with a wide variety of other commodities. When viewed from the perspective of the ability of inland waterways to support enhanced export opportunities that a global fleet of larger ocean going vessels represent, those inland waterways that serve a hinterland with desirable export commodities are of particular interest. This directs focus to the Upper Mississippi, Illinois, Ohio (and its tributaries), and the Columbia-Snake rivers and the Great Lakes and the ports they serve.

[19] These major ports are selected from among the top 150 ports by tonnage as identified by the USACE Waterborne Commerce Statistics Center.

Port and Waterway Infrastructure

The state of port infrastructure at both the point-of-shipment in the U.S. and at the point of destination can be limiting factors. For grains, Pacific Northwest, Center Gulf (Lower Mississippi River) and Texas Gulf terminals are capable of accommodating the loading of large vessels of any size. Each is configured to handle grain in large volumes by rail and river at the PNW, largely by rail in the Texas Gulf, and mostly by river in the Center Gulf region. Ports in Northeast Asia receiving grains are currently maintained at depths compatible with current Panama Canal depths and the depths of nearly all U.S. ports. Though capital investments are planned for some of these ports, at the current time they act as a limiting factor to the same extent as the depth of U.S. ports.

Deep draft ports handling ores and coal in Northeast Asia are designed to handle the largest ore and coal carriers. Only LA/Long Beach, Oakland, and Seattle/Tacoma on the West Coast and Baltimore and Norfolk on the East Coast have depths of 50 feet or more, limiting the potential use of fully loaded vessels drafting 50 feet to these four ports. In fact, the new Panama Canal locks are too small to handle the largest of the ore and coal carriers, making it a limiting factor on an Atlantic or Gulf Coast trade route to Asia. China continues to propose projects and make investments in ports (a deepwater bulk port in Brazil) and overland infrastructure (a rail connector proposed for linking Colombian coal fields on the Atlantic side of the country to a Pacific port) in South America that allow them to maximize their use of these vessels. These investments improve the competitive position of Brazil as an ore and soybean exporter and Colombia as a coal exporter relative to the U.S.

Interestingly, the reliability of lock and dam structures is linked to both highway and rail performance in a demonstration of the interconnected nature of the transportation system. Lock outages at the Nation's aging system of locks and dams have experienced a sharp increase over the last 20 years. Much of this is related to outages either for scheduled or unscheduled lock repairs. Carriers face lost opportunities and increased costs due to these disruptions that delay service, while shippers face potential disruptions to their operations and increased transportation costs as they seek ways to work around lock facilities either closed to traffic or experiencing major congestion as traffic moves through smaller auxiliary chambers (when available). During closure events, shippers will seek alternative overland routes, which can cause congestion on these routes (rail or truck).

Surface Transportation System

The maritime aspects of trade, whether domestic or foreign, inland vessel or ocean going ship, are part of a multi-modal system for the movement of bulk commodities from point of production to point of consumption. A complete examination of the inland system's capability to accommodate future flows of traffic also needs to consider the capability of other parts of this multi-modal system. Whether truck, rail, barge, Lake Vessel or ocean freighter, each mode is dependent upon the other if the system is to operate efficiently. When this occurs, more markets are available to producers and the nation enjoys the benefit of the efficiencies incurred.

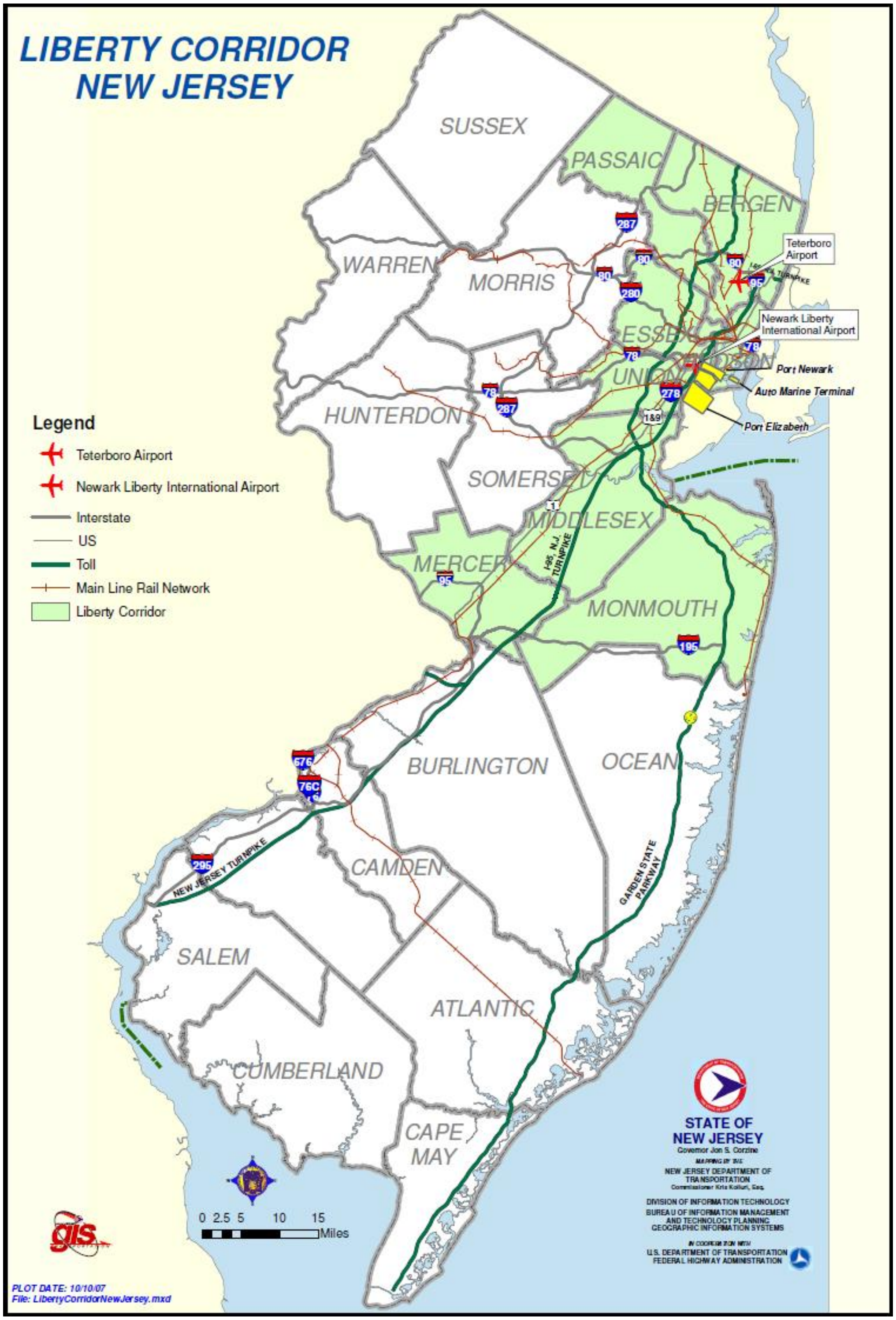
Much of the information presented in this discussion relies upon the *Study of Rural Transportation Issues,* a report prepared for the U.S. Department of Agriculture and the U.S. Department of Transportation and published in 2010.

Truck

The trucking industry carries nearly three quarters of all agricultural products and is the sole mode of freight service for more than 80 percent of all communities in the U.S. Trucks are critical to the efficient movement of goods in the U.S., often making the first and/or last move in most supply chains, including those for coal and grains. This highly competitive industry has over 691,000 companies (over half of which own one truck), keeping truck rates relatively low. Operating costs are 95 percent of revenue, making trucking firms' rates sensitive to increases in operating costs, whether from fuel prices or operating requirements stemming from a patchwork of local, state and Federal regulations.

The capacity of this mode is dependent upon: 1) drivers, 2) trucks and 3) roads. The availability of drivers can in the short run be constrained due to the need for training and licenses. National laws dictate driver requirements, such as daily hours in service, licensing, or identification and security requirements. Trucks are currently available in great numbers; some 3,000 trucking companies went out of business during the recession. Carrying capacities are determined by payload dimensions and highway and bridge weight restrictions. The Federal government sets weight and size restrictions on the Interstate Highway System and fixes the maximum width, while placing limits to the restrictions that states can place on highways designated as part of the National Highway Network.

To increase capacity and remove bottlenecks, states are developing "corridor" projects. In New Jersey, the Liberty Corridor of New Jersey is a multi-modal transportation system tying ports, highways, airports and rail lines together to make critical connections and clear chokepoints. Figure 25 below depicts the Liberty Corridor.



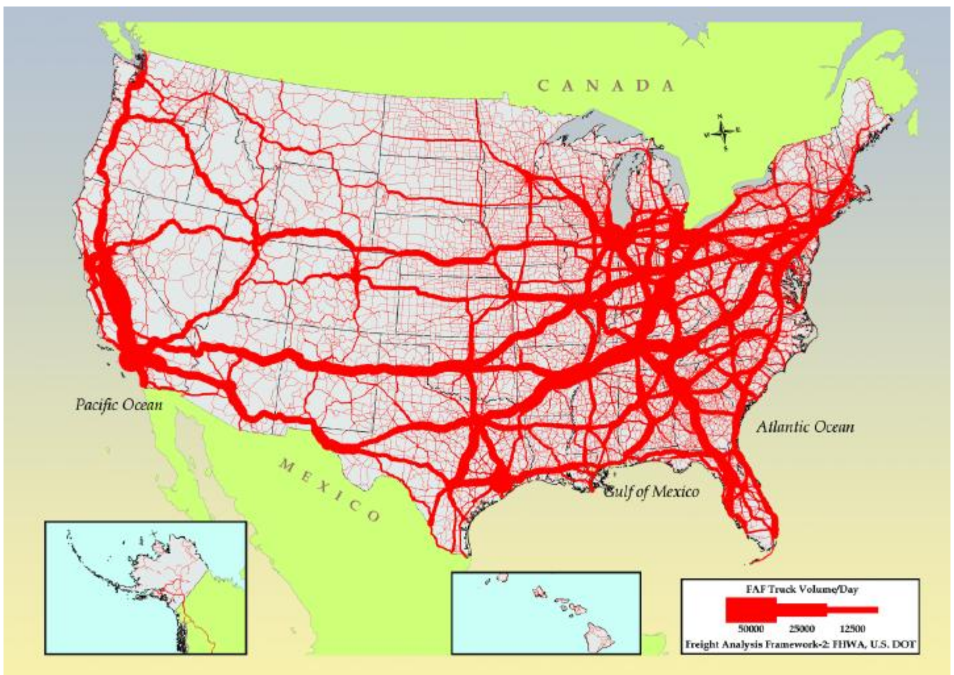
Source: New Jersey DOT

Figure 25: Liberty Corridor, New Jersey

Road condition, which can lead to the weight restrictions mentioned above, and congestion are also limiting factors on the mode's capacity. The U.S. Department of Transportation, Federal Highway Administration's *2010 Status of the Nation's Highways, Bridges, and Transit: Conditions*

& Performance, January 2010, reported that over half of all vehicle miles travelled are on highway pavement providing less than good rides and more than a quarter of the Nation's bridges are structurally impaired or obsolete.

Most observers do not report roadway congestion as a problem for grain and coal shippers, since most miles are travelled in rural areas. Congestion issues can become an issue for grain and coal shippers when hauling long distances to terminals near urban areas and could be a major issue in the event of lock outages should the shipper decide to truck around the obstacle and need to take a route through urban areas like St. Louis, MO or Cincinnati, OH. (See Figure 26, for a description of average daily long-haul truck traffic.)



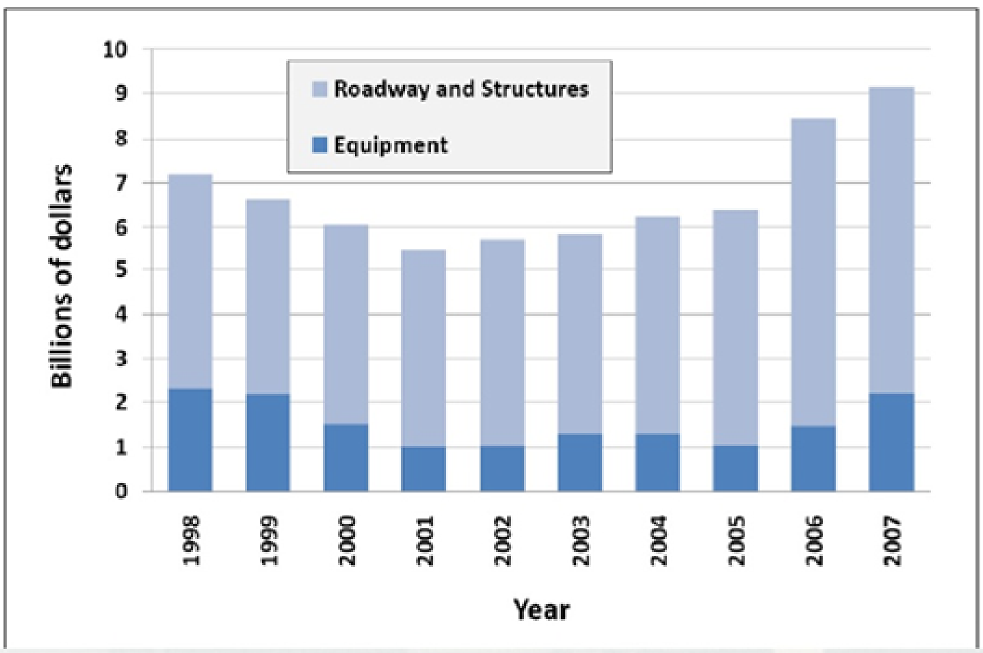
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, Version 2.2. 2007

Figure 26: Estimated Average Daily Long-Haul Truck Traffic on the National Highway System (2005)

Rail

U.S. railroads have steadily increased investments in both road and equipment. The $9 billion invested by the railroads in 2007 was a 27 percent increase over what was invested in 1998. Western railroads, spurred by growth in Northeast Asia, increased capital expenditures by nearly a third over this timeframe (see Figure 27). These investments build capacity and improve performance of their land bridge between West Coast ports and production areas in the interior and consumer markets in the Midwest and East Coast.   These investments allow West Coast ports to compete with Gulf Coast ports for grain (and potentially coal) export shipments out of the U.S. to Asia and improve the overall U.S. position globally in both the grain and coal export markets. Proposed coal terminal facilities on the Columbia River near Portland in Oregon and

Washington and at Cherry Point in Washington State (each with planned annual throughput capacity of roughly 30 million tons and representing an investment in excess of $500 million) are indicators of the private sector's view of the potential that exists in the Asian coal market. These terminal facilities would provide the capability of handling coal in the volumes required by *Panamax* or *post-Panamax* vessels of any kind. Railroad investments are made possible by the financial health of the major rail carriers. A return to profitability for the industry was made possible by the Staggers Act of 1980, which deregulated railroads. Deregulation allowed the railroads to abandon low revenue lines, initiate mergers that removed redundancies, change terms of service, and initiate differential pricing for service. With the elimination of excess capacity and introduction of efficiencies like the shuttle train, railroads' return on investment improved dramatically, allowing them to invest in high-use, high-return rail lines. Revenues rose while rates fell over the 20 years following Staggers. It was only in the early 2000s that rates began to rise as traffic grew at a pace faster than railroads could add capacity. Rates continued to increase until the recession that began in December 2007.

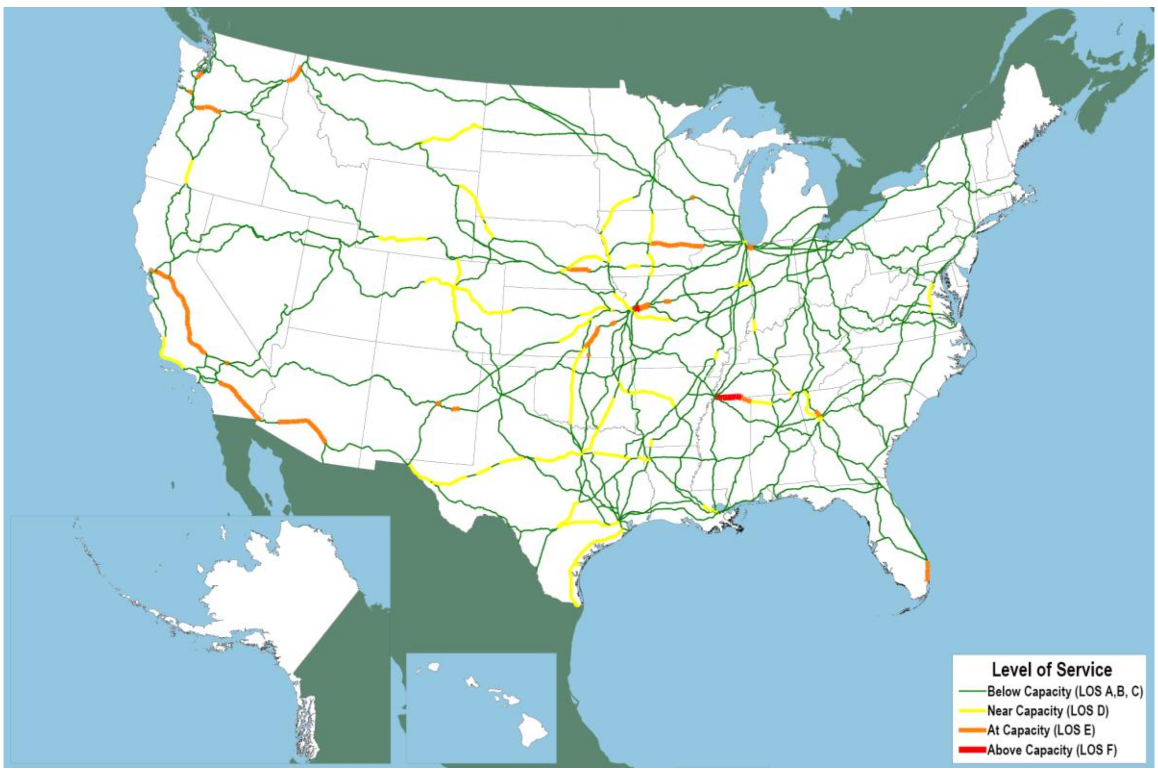


Source: AAR, Analysis of Class I Railroads

Figure 27: Class I Railroad Capital Expenditures

Railroad service and pricing revolve around the railroads' efforts to improve speeds and efficiency, and to shift costs. They have done this by investing in access lanes to the ports (like the Alameda Corridor), in more equipment, more track, and more unit and shuttle trains, and by abandoning some feeder lines. Some of the cost risks have been shifted to the shipper. In the coal market entire trains are now owned by the shipper, while grain shippers often own the cars. Collection costs have been shifted to the coal producer and to the farmer, leading some of them to move goods by truck a longer distance on rural roads to terminals that load out unit and shuttle trains. In addition to placing an additional cost burden on the producer, state and local governments need to cover the additional maintenance costs on rural highways. A similar phenomenon is occurring with the relatively new container trade for grains where farmers must travel to find empty containers and then transport them to often distant assembly points near large population centers.

Efficiency gains allowed railroads to move 171 percent more traffic than in 1980 despite having fewer miles of track. The railroads have made massive investments, and have adequate locomotives, cars and operators. The map below (Figure 28) shows major rail lines and the capacity of each relative to the traffic each carried in 2007. Many lines in the grain producing area are near capacity, with a number of connecting lines at capacity and one line along the Tennessee-Mississippi border over capacity. With economic recovery and the return of higher traffic volumes, many of these near capacity lines could become bottlenecks, particularly if the Panama Canal expansion and advent of larger oceangoing vessels encourages the movement of grains to the Gulf. Eastern railroads do not indicate widespread capacity issues with one important exception in Virginia.

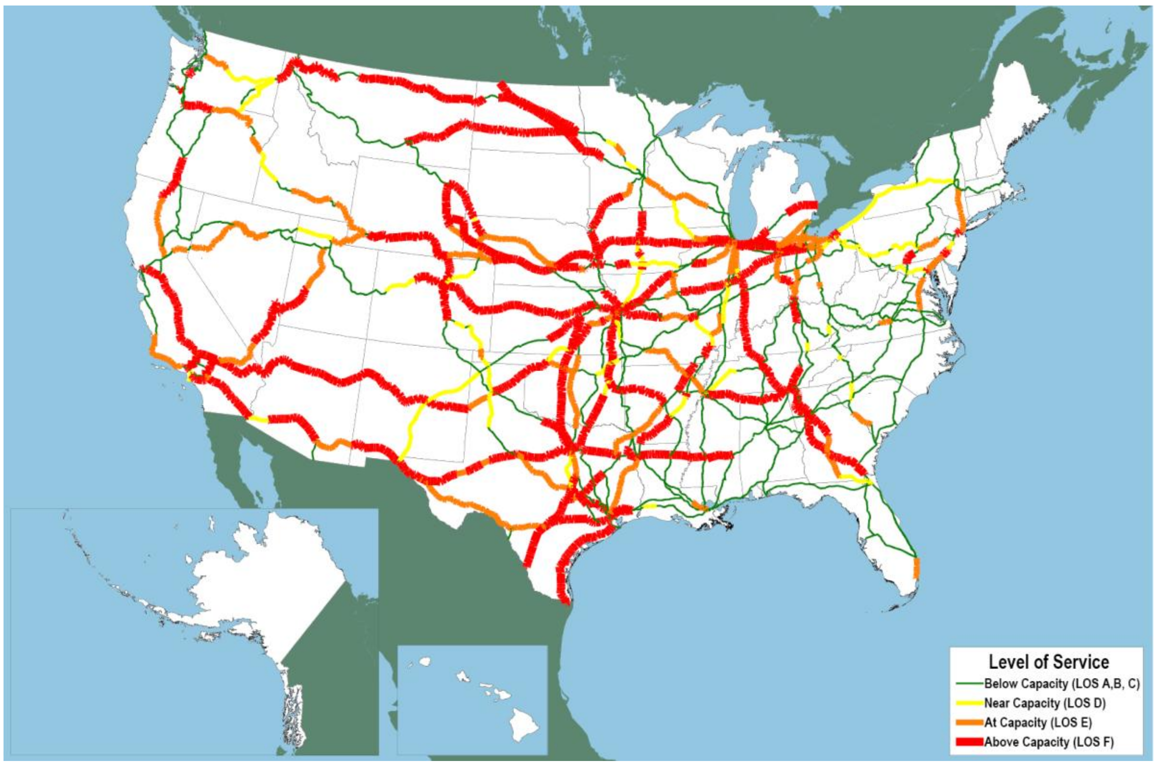


Note: Level of Service (LOS) A through F approximates the conditions described in Transportation Research Board, *Highway Capacity Manual 2000*

Source: "National Rail Freight Infrastructure Capacity and Investment Study"-Cambridge Systematics, Inc. 2007

Figure 28: 2007 Rail Performance

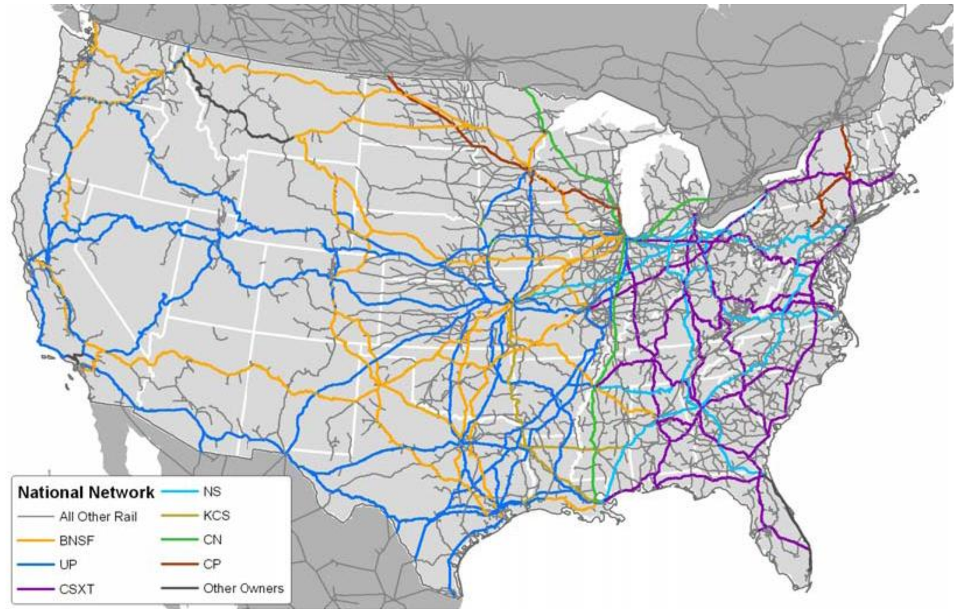
Some analysts project major bottlenecks throughout the system by 2035, others see rail demand easing. Nevertheless, it is apparent that periods of bottlenecks, especially for grain given the seasonal nature of its movement, may occur are likely unavoidable and reason for concern if the U.S. is to remain a reliable supplier of grain to the world. Without rail capacity improvements, Cambridge Systematics, Inc. projected widespread rail congestion by 2035 (Figure 29). This analysis shows that 45 percent of primary corridor mileage will be below capacity, 25 percent near or at capacity, and 30 percent above capacity. The analysis is dependent upon traffic forecasts and trade volumes that return to rates of growth experienced before the recession of 2008/2009. It is important to note that peak or seasonal flows are not considered.



Note: Level of Service (LOS) A through F approximates the conditions described in Transportation Research Board, *Highway Capacity Manual 2000.*

Source: "National Rail Freight Infrastructure Capacity and Investment Study"-Cambridge Systematics, Inc. 2007

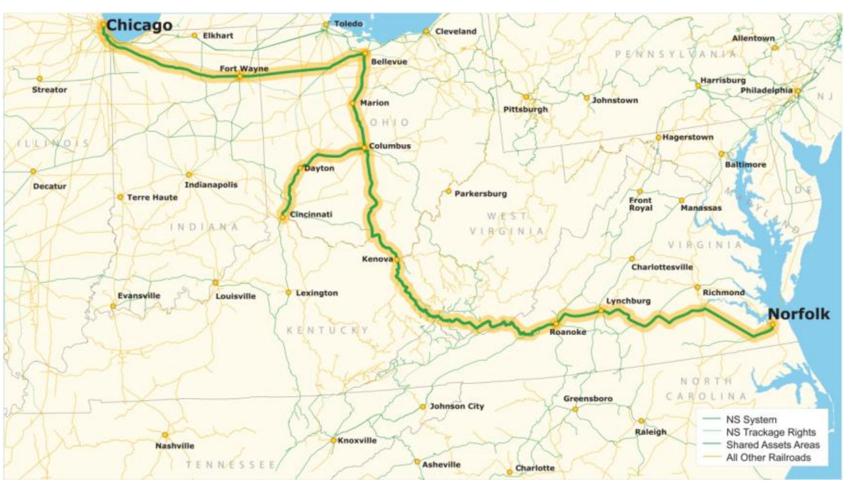
Figure 29: Potential Rail Performances in 2035



Source: "National Rail Freight Infrastructure Capacity and Investment Study"-Cambridge Systematics, Inc. 2007

Figure 30: Railroad Freight Network

Figure 30 describes the national railroad freight network. The Heartland Corridor (Figure 31) is a public-private partnership between the Norfolk Southern Railway (NS) and the Federal Highway Administration and three U.S. states to improve railroad freight operations.[20] The plan was developed to facilitate more efficient travel on NS rail lines between the Norfolk, VA port region to Columbus, OH and Chicago, IL. The project goals increase tunnel clearances to permit the operation of double-stacked. The Crescent Rail Corridor (Figure 32) is also operated by the Norfolk Southern Railway. The Crescent Corridor will run along Interstate 81 and will be an intermodal corridor between Louisiana and New Jersey.



Source: Norfolk Southern (MARAD Panama Canal Expansion, Phase 1 Report)

Figure 31: Heartland Corridor

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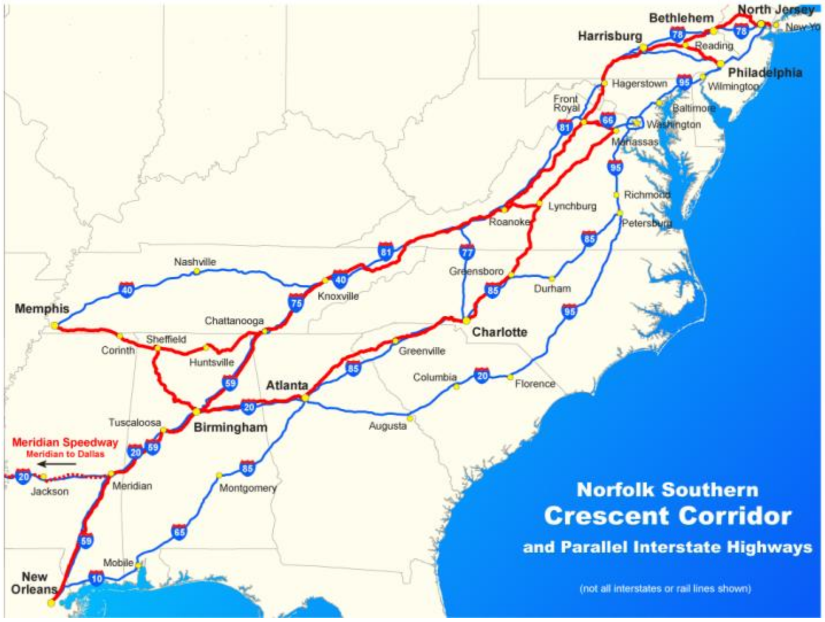
[20] Norfolk Southern opens Heartland Corridor. Railway Gazette International, September 9, 2010.



Source: Norfolk Southern (MARAD Panama Canal Expansion, Phase 1 Report)

Figure 32: Crescent Corridor

Chapter 3: Evaluating Capacity Maintenance and Expansion

The desirability for maintenance and expansion of the Nation's navigation transportation capacity is derived from the demand for transportation services. This demand is tied to population and income, as shown in chapter 1. Forecast growth of population and income imply growth in trade and the demand for transportation services. However, it is difficult to predict the extent of this future growth, and when and where it will happen.

As suppliers of transportation services compete, they seek economic advantage. Advantage is gained in deep draft navigation through more efficient vessels, cargo handling techniques, and inter-modal connectors. The greatest manifestation of this has been the innovation of containerized cargo and the container vessel.

Since the introduction of the container in 1956,[21] containerized trade has grown to tens of millions of TEUs per year. This growth in containerized trade has led to the building of vessels designed to carry them. The increase in the size of container vessels can only be described as phenomenal—growing from a fleet size of just 6.375 million TEUs in 1990 to an estimated 32.185 million TEUs in 2012.[22] Maximum vessel size has increased from about 7600 TEUs in 2000 to about 14,000 TEUs in 2012 with 18,000 TEU vessels on order for delivery in 2013. These large vessels present economic efficiencies largely through reduced fuel consumption per ton mile. This becomes also an environmental opportunity as reduced fuel consumption per TEU results directly in reduced emission per TEU.

This chapter reflects on the future need for capacity at the Nation's ports and inland waterways resulting from the deployment of *post-Panamax* vessels in the world fleet. It qualitatively considers the likely forecast scenarios to impact each port or region and considers the scenario most likely to prevail in the future given our current understanding of the industry and whether a port or region has a need for additional maintenance or expansion to be able to meet the needs of the forecast scenario.

Market Responses

The Panama Canal expansion is expected to be completed in 2014. The expansion has been called a "game changer." Its influence will be great, yet there is uncertainty regarding the

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[21] Levinson, Marc. 2006. The Box – How the Shipping Container Made the World Smaller and the World Economy Bigger. Chapter 1, page 1.

[22] World Container Traffic - Drewry Annual Reports; End Year Fleet Size - CI Market Analysis: Container Leasing Market 2010 as quoted in World Shipping Council, Container Supply Review May 2011.

specifics of how and when the game will change. There are three primary responses expected from the expansion. [23]

West Coast Diversions

West Coast ports serve as an alternative to the Panama Canal. The intermodal land bridge formed by the rail connections to West Coast ports provides a faster connection from and to Asian markets. Typically the land bridge is estimated to be five to six days faster, an advantage that can't be entirely made up on an all-water route through an expanded Panama Canal. However, with the expansion of the Panama Canal, the cost of using the all-water route from Asia to the East Coast is reduced and may be enough to off-set the increased transit time and result in traffic diverting from West Coast to East Coast ports in some cases.

Transshipment

Ports in the U.S. and Caribbean that are currently capable of receiving the largest of the *post-Panamax* vessels, when fully loaded, become deepwater transport hubs for vessels of all sizes. On the West Coast, these large vessels can call at Seattle, Oakland and LA/LB. On the East Coast, large vessels can or will be able to call at Norfolk, New York/New Jersey, Baltimore and Miami. These ports and *post-Panamax* ready ports in the Caribbean serve as transport hubs. The largest vessels unload at the hub and smaller feeder vessels deliver to ports with less channel capacity.

Agricultural Exports

The Panama Canal enlargement may make shipment of Midwest grains and other goods through Gulf ports to Asian markets more attractive than existing routes. That may, or may not, increase total U.S. exports of these products. However, it would increase barge traffic down Mississippi tributaries to the Gulf of Mexico.

There is uncertainty in these market responses. Details of when *post-Panamax* vessels will arrive in large numbers, at which ports they will call, how deep vessels will draft and, consequently, how deep and wide navigation channels and other related navigation infrastructure must be are uncertain. Another key uncertainty is the future Panama Canal Authority (ACP) toll structure. It should be noted that deepening U.S. ports to service *post-Panamax* vessels that transit the Panama Canal enhances the ability of the ACP to benefit through increases in its toll structure. In fact, it may be possible for the ACP to extract a majority of the transportation cost savings benefits on routes that use the canal, limiting the cost savings associated with the use of larger vessels through the canal that will be available to carriers, shippers, producers or consumers. A careful understanding of this is required when choosing which ports to deepen and how to finance the project.

[23] This scenario discussion in this chapter owes a great debt of gratitude to the work presented in the MARAD *Panama Canal Phase I* report.

Another key uncertainly is the role that transshipment hubs in the Caribbean or on U.S. shores could play in transferring freight from large vessels to smaller feeder vessels. Transshipment might offer cost savings to cargo headed for ports that are not *post-Panamax* ready. However, transshipment hubs add time and extra handling and additional exposure to the harbor maintenance tax, costs that may exceed the benefits of using a larger vessel.

As noted, reduced costs for an all-water route from Asia to the East Coast could cause a shift of some market share from the West Coast ports to the East Coast. However, given the expected overall increase in trade, it is not a zero sum game. Even if West Coast ports were to lose some market share, they will still see an increase in cargo moving through their ports. Moreover, West coast ports and their rail partners are investing heavily to increase the capacity and efficiency of the intermodal land bridge to ensure it remains competitive and retains market share.

It should be remembered that the opportunities for reduced costs available to U.S. agricultural exports through the use of larger bulk carriers are also available to its competitors in international markets.

Impact Scenarios

Impact scenarios have been derived by varying the three expected market responses. Using non-quantified descriptors of high and low for each response, eight scenarios were developed.

Table 7: Impact Scenarios

Post-Panamax Vessel Impact Scenarios			
	West Coat Diversion	Transshipment	Agricultural Exports
Scenario 1	H	H	H
Scenario 2	H	H	L
Scenario 3	H	L	H
Scenario 4	H	L	L
Scenario 5	L	H	H
Scenario 6	L	L	H
Scenario 7	L	L	L
Scenario 8	L	H	L

Scenario One – Under this scenario significant traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are high, either at *post-Panamax* ready U.S. ports or Caribbean ports. The impact on agricultural exports is also high resulting in more grain being exported through U.S. Gulf ports.

Scenario Two – Under this scenario significant traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are high, either at *post-Panamax* ready U.S. ports or Caribbean ports. The impact on agricultural exports is low with little impact on grain being exported through U.S. Gulf ports.

Scenario Three - Under this scenario significant traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are low, large vessels use *post-Panamax* ready U.S. ports but other ports are served by smaller vessels. The impact on agricultural exports is also high resulting in more grain being exported through U.S. Gulf ports.

Scenario Four - Under this scenario significant traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are low, large vessels use *post-Panamax* ready U.S. ports but other ports are served by smaller vessels. The impact on agricultural exports is low with little impact on grain being exported through U.S. Gulf ports.

Scenario Five - Under this scenario little traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are high, either at *post-Panamax* ready U.S. ports or Caribbean ports. The impact on agricultural exports is also high resulting in more grain being exported through U.S. Gulf ports.

Scenario Six - Under this scenario little traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are low, large vessels use *post-Panamax* ready U.S. ports but other ports are served by smaller vessels. The impact on agricultural exports is also high resulting in more grain being exported through U.S. Gulf ports.

Scenario Seven - Under this scenario little traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are low, large vessels use *post-Panamax* ready U.S. ports but other ports are served by smaller vessels. The impact on agricultural exports is low with little impact on grain being exported through U.S. Gulf ports.

Scenario Eight - Under this scenario little traffic is diverted from the West Coast ports and the intermodal land bridge to the East Coast ports. Transshipments are high, either at *post-Panamax* ready U.S. ports or Caribbean ports. The impact on agricultural exports is low with little impact on grain being exported through U.S. Gulf ports.

Over time the uncertainties with the market response to the Panama Canal improvements will be reduced as experience replaces expectation. IWR does not consider transshipment hubs likely to serve as the primary avenue of foreign imports or exports. As shown in Figure 33, the all-water route to the East Coast already adds 8 to 12 days to delivery. The Panama Canal toll will take a part of the transportation cost savings. A transshipment hub would add more cost and further increase delivery time. As noted in Chapter 2, the railroads are investing heavily, which will help maintain their competitiveness. These factors seem to weigh against the development of any substantial transshipment hub. In the absence of transshipment centers, *post-Panamax* vessels will call at the ports that are able to accommodate them, and the number of times that they call at each of these ports, their sailing drafts and other dimensions will become known.

However, this kind of a hub and spoke model has reduced airline passenger costs and air freight costs, so the option may be deserving of more analysis. Overall, it could be more economical for some routes and would involve less Federal spending and fewer adverse environmental impacts. The potential barriers include the cost to alter port facilities to accommodate transshipment, additional cargo handling costs, higher shipping costs due to cabotage, and the harbor maintenance tax.[24]

Source: Parsons Brinckerhoff, 2011 (MARAD Panama Canal Expansion, Phase 1 Report)

Figure 33: Travel time comparisons from Asia to Pacific and Atlantic Coast destinations

Getting Ready for *post-Panamax* Vessels

The U.S. population is expected to increase 32 percent from 313.4 million people in 2011 to 412.2 million in 2042, as shown in chapter 2. The two regions expected to grow the most by

[24] GAO, Freight Transportation: Short Sea Shipping Shows Importance of Systematic Approach to Public Investment Decisions, GAO-05-768 (July 2005).

2030 are the South at 43 million and the West at 29 million. IHS-GI has forecast U.S. imports to grow from $2,666 billion in 2011 to $12,444 billion in 2042 to support this population growth. Exports are projected to increase from $2,088 billion to $14,831 billion over the same time period.

San Pedro Bay TEU traffic, representative of West Coast port expectations, is expected to grow to 36.7 million TEUs by 2030. On the East Coast containerized tonnage is expected to grow from 65.66 million tons in 2012 to 146.3 million tons by 2029.

Gulf Coast containerized tonnage is expected to grow from 29.6 million tons in 2012 to 64.6 million tons by 2029.

One-half of the growth in Center Gulf bulk exports is expected to use the Panama Canal and it is projected that the Center Gulf will increase its share of total U.S. exports over the next 10 years. These exports will transit the Mississippi River to the Port of New Orleans.

Carriers are expanding their fleet of vessels with larger ships to serve the current and future global demand. By 2030 p*ost-Panamax* vessels could represent 62 percent of the total TEU capacity of the container vessel fleet. *Post-Panamax* vessels are already calling at some U.S. ports and will call with increasing regularity in the future. The challenge is to invest in capacity expansion in the right places, at the right time, and in the right way in response to the Panama Canal improvements.

> The term "*post-Panamax* ready" has to be defined for individual ports. Even as the *post-Panamax* fleet varies in length, width and sailing draft, so too will the required land side facilities, turning basins, channel depths and widths vary at each port to accommodate the characteristics of the specific fleet calling at that port. It is not necessary to be able to accommodate the larger classes of *post-Panamax* vessels to be considered *post-Panamax* ready.

For this report, a port is be considered "*post-Panamax* ready" if it has a channel depth of about 50 feet net of allowances for usable tide, as well as sufficient dock and crane capacity. U.S. West Coast ports at Seattle, Oakland, Los Angeles and Long Beach all have 50-foot channels. Northeastern U.S. ports at Baltimore and New York have or will soon have 50-foot channels. On the Southeast coast, Norfolk has a 50-foot channel. Below Norfolk along the U.S. Southeast and Gulf Coasts, there are no ports with 50-foot channels, although Charleston with a 45-foot channel depth and nearly 5 feet of tide can accommodate most *post-Panamax* vessels. This is also a region with high forecast population and the associated potential for trade growth. To respond to these needs, Miami is deepening their channel and will soon have 50-foot channel depth.

In order to prevent ports from becoming the limiting component of the navigation system, the vision for the system must extend beyond the major ports to include lower tier ports. New, large vessels are typically deployed on the longest and largest trade service – Asia to Northern Europe. The "smaller" vessels on that service are forced to re-deploy to the next most efficient service for that vessel size. This cascading continues until the most marginal vessels in the fleet are forced to be scrapped. Cascading typically increases average vessel size for each trade service, placing demands on the port infrastructure to support larger capacity vessels. For U.S. ports to be ready to take advantage of *post-Panamax* vessel opportunities, major ports not only need to be "*post-Panamax* ready," but second tier ports need to be "cascade ready" as they in turn have the opportunity to take advantage of larger vessels that begin to service their trade. For the purposes of this report IWR defines "cascade ready" as a channel depth of 45 feet.

Table 8 shows major U.S. ports and their channel depth tidal range by region.

Table 8: U.S. Ports with Channel Depths and Tidal Range by Region

State	Project	Coast	Region	Depth, ft	Neap Tidal Range, ft	Present Container Port	Post-Panamax Ready
MA	BOSTON HARBOR, MA	Atlantic	NE	40	8.7	Yes	N
MD	BALTIMORE HARBOR AND CHANNELS	Atlantic	NE	50	0.6	Yes	Y
ME	PORTLAND HARBOR	Atlantic	NE	35	8.3	Yes	N
NJ	NEWARK BAY (HACKENSACK AND PASSAIC RVS) NJ	Atlantic	NE	50	4.5	Yes	Y
NY	BAY RIDGE AND RED HOOK CHANNELS, NY	Atlantic	NE	40	4.0	Yes	N
NY	BUTTERMILK CHANNEL	Atlantic	NE	40	4.0	Yes	N
NY	EAST RIVER	Atlantic	NE	40	6.5	Yes	N
NY	HUDSON RIVER CHANNEL	Atlantic	NE	45	4.0	Yes	N
NY	NEW YORK HARBOR	Atlantic	NE	50	4.0	Yes	Y
NY	NYNJ CHANNELS (ARTHUR KILLKILL VAN KULL)	Atlantic	NE	50	4.2	Yes	Y
PA	DELAWARE RIVER, PHILADELPHIA TO THE SEA	Atlantic	NE	40	5.0	Yes	N
PR	SAN JUAN HARBOR, PR	Atlantic	NE	39	0.6	Yes	N
RI	PROVIDENCE RIVER AND HARBOR	Atlantic	NE	40	4.0	No	N
VA	CHANNEL TO NEWPORT NEWS, VIRGINIA	Atlantic	NE	50	2.1	Yes	Y
VA	NORFOLK HARBOR, VIRGINIA	Atlantic	NE	50	2.1	Yes	Y
VA	THIMBLE SHOAL CHANNEL, VA	Atlantic	NE	50	2.2	Yes	Y
	DEL R PHILADELPHIA TO TRENTON	Atlantic	NE	40	7.3	Yes	N

	DELAWARE RIVER AT CAMDEN	Atlantic	NE	40	5.7	Yes	N
FL	CANAVERAL HARBOR FL	Atlantic	SE	41	2.9	Yes	N
FL	JACKSONVILLE HARBOR FL	Atlantic	SE	40	1.7	Yes	N
FL	MIAMI HARBOR FL	Atlantic	SE	42	2.2	Yes	N
FL	PORT EVERGLADES HARBOR	Atlantic	SE	42	2.2	Yes	N
GA	BRUNSWICK HARBOR, GA	Atlantic	SE	36	6.0	No	N
GA	SAVANNAH HARBOR	Atlantic	SE	42	6.3	Yes	N
NC	MOREHEAD CITY HARBOR NC	Atlantic	SE	45	2.7	No	N
NC	WILMINGTON HARBOR NC	Atlantic	SE	42	3.9	Yes	N
SC	CHARLESTON HARBOR SC	Atlantic	SE	45	4.7	Yes	With tide
AL	MOBILE HARBOR	Gulf	Gulf	45	1.3	Yes	N
FL	MANATEE HARBOR	Gulf	Gulf	40	0.9	Yes	N
FL	PANAMA CITY HARBOR	Gulf	Gulf	36	1.2	Yes	N
FL	TAMPA HARBOR FL	Gulf	Gulf	43	0.9	Yes	N
LA	CALCASIEU RIVER AND PASS	Gulf	Gulf	40	0.6	No	N
LA	MISS RIVER BATON ROUGE TO GULF	Gulf	Gulf	45	1.2	Yes	N
MS	GULFPORT HARBOR, MS	Gulf	Gulf	36	1.4	Yes	N
MS	PASCAGOULA HARBOR	Gulf	Gulf	42	1.2	Yes	N
TX	BARBOUR TERMINAL SHIP CHANNEL	Gulf	Gulf	42	1.0	Yes	N
TX	BAYPORT SHIP CHANNEL	Gulf	Gulf	42	1.0	Yes	N
TX	BRAZOS ISLAND HARBOR	Gulf	Gulf	42	1.0	No	N
TX	CORPUS CHRISTI SHIP CHANNEL	Gulf	Gulf	45	1.0	No	N
TX	FREEPORT HARBOR	Gulf	Gulf	45	1.0	No	N
TX	GALVESTON HARBOR AND CHANNEL	Gulf	Gulf	45	1.0	No	N
TX	HOUSTON SHIP CHANNEL	Gulf	Gulf	45	1.0	Yes	N
TX	SABINENECHES WATERWAY	Gulf	Gulf	42	0.6	No	N
TX	TEXAS CITY CHANNEL	Gulf	Gulf	45	1.0	No	N
AK	ANCHORAGE HARBOR, AK	Pacific	Pacific	35	23.2	Yes	N
CA	LOS ANGELESLONG	Pacific	Pacific	53	2.2	Yes	Y

	BEACH HARBORS						
CA	OAKLAND HARBOR	Pacific	Pacific	50	3.1	Yes	Y
CA	PORT HUENEME	Pacific	Pacific	36	1.9	No	N
CA	SAN DIEGO HARBOR	Pacific	Pacific	47	2.4	No	With tide
CA	SAN FRANCISCO HARBOR	Pacific	Pacific	40	2.4	N/A	N
OR	COLUMBIA RIVER AT MOUTH, OR AND WA	Pacific	Pacific	48	4.9	Yes	Y
OR	COOS BAY OR	Pacific	Pacific	37	3.8	Yes	N
WA	C AND LW RIVERS BELOW VANCOUVER WA AND PORTLAND OR	Pacific	Pacific	43	1.8	Yes	N
WA	GRAYS HARBOR, WA	Pacific	Pacific	36	4.9	Yes	N
WA	SEATTLE HARBOR, WA	Pacific	Pacific	50	4.0	Yes	Y
WA	TACOMA HARBOR	Pacific	Pacific	51	4.4	Yes	Y

Source: USACE Institute for Water Resources

The need for capacity expansion is likely to be the most critical along the U.S. Southeast and Gulf Coasts. This is indicated by the growth in population and trade as well as the lack of current capacity. South of Norfolk there are no ports that are fully *post-Panamax* ready. The ports of Savannah, Charleston and Miami are at various stages of capacity expansion. Successful development at these ports would fill the critical need on the Southeast coast. However, there may be a need for "cascade ready" expansion at some of the smaller ports.

There are 10 deep draft navigation projects along the Gulf Coast with container yards and related infrastructure. Depths of these projects range from 36 to 47 feet. None of these ports is considered *post-Panamax* ready. Several ports in the Gulf are under study to deepen their channels to be better prepared for larger drafting vessels, including the Mississippi River from Baton Rouge to the Gulf and the Texas ports of Freeport, Corpus Christi and Island Harbor in Brownsville. A recently completed study of a proposal for Sabine Neches estimated that deepening its channel to 50 feet would cost more than $1 billion and would yield a positive economic return. On the Gulf coast the lack of channel depth is exacerbated by the small tidal window, which is generally one to two feet.

There may also be opportunities at other ports around the country to increase the width of channels and turning basins to accommodate the longer, wider design of new container vessels.

How Much Depth Is Needed?

In the past, larger vessels have always meant deeper drafts. This is the nature of bulk vessels and for a time held for container vessels as well. However, recent designs in container vessels have tended towards longer, wider vessels with "U" shaped as opposed to "V" shaped hulls. Maersk, the largest carrier in the world, has recently introduced two classes of these new designs. The *Maersk Triple E*, scheduled to begin deployment in 2013 will carry 18,000 TEUs. Its physical dimensions are 1,300 feet long, 194 feet wide with a design draft of 47.6 feet. This compares to the *Emma Maersk*, formerly the largest containership in the world, a 15,000 TEU capacity vessel with a 51 foot draft. The second vessel design may be of more interest. Maersk's SAMMAX vessel, designed to take advantage of the expanded Panama Canal for the South American trade, was designed to carry 7,450 TEUs.[25] Maersk has ordered 16 of these vessels. Two were put into service in 2011. The vessels measure 984 feet long and have a beam of 147 feet. Their design draft is only 39 feet. Maersk claims these vessels are 8 percent more efficient than other vessels of similar capacity. If these designs prove to be effective there will likely be other intermediate sizes designed for other markets.

Weight Trade and Volume Trade Services

The maximum capacity of container vessels can be limited by either the maximum vessel sailing draft or by the number of containers they can carry. Depending upon the weight of cargo in the containers, this limit can either be by weight (maximum draft) or volume (slot capacity). That is, lighter cargo will draft less than heavier cargo for the same number of containers. This can be measured by cargo density, i.e., the average weight per container on a vessel expressed as metric tons per TEU. Cargo density is expected to vary dependent upon the commodities handled by different trade routes. Vessels operating on trade routes from foreign ports that typically ship lighter commodities are expected to have lower cargo densities and thus will arrive at U.S. ports drafting less than their design draft. Other factors that can affect containership loading include limitation due to line of site and lashing requirements.

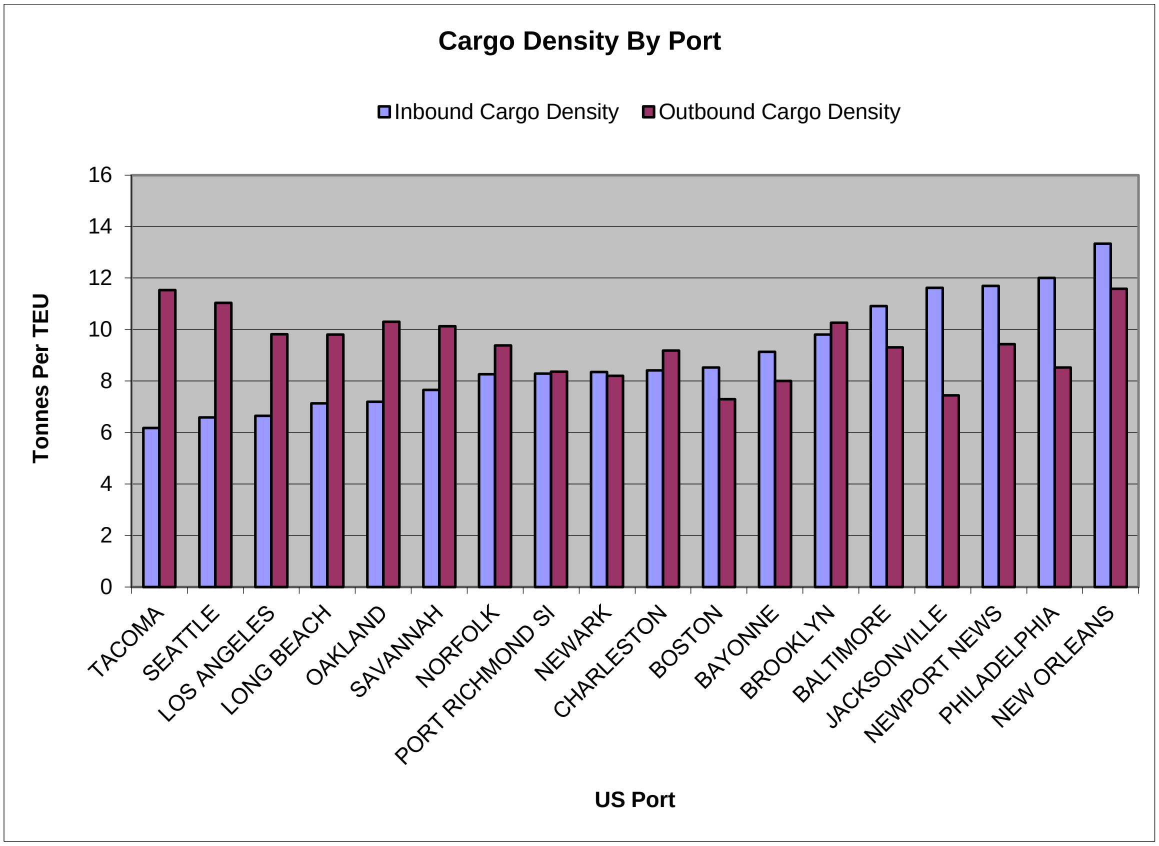
IWR has performed an analysis of vessel trade data for U.S. ports to examine the issues of cargo density by port, trade route and vessel class. The methodology involved use of two comprehensive data sources: 1) information collected on waterborne commerce by IWR's Waterborne Commerce Statistics Center (WCSC) and 2) automated identification system (AIS) data on global container vessel movements, previously acquired from the private maritime data provider Lloyd's Register–Fairplay, now IHS Fairplay. AIS data allows analysis of container vessel movements over time to determine trade routes, but does not contain any information on cargo transfers. WCSC data supports analysis of cargo transfers by weight and volume at U.S. ports, but does not provide information on global vessel movements. Combined, the two data sources provide a picture of historical vessel movements and can be used to estimate cargo density of container vessels by vessel class and trade route.

The cargo density analysis was carried out utilizing AIS 2006 to 2008 data and WCSC 2006 to 2009 data. AIS data was matched with WCSC data for the period 2006-2008 to provide cargo transfer information that could be analyzed at the service level. WCSC data for the full period of availability (2006-2009) was analyzed at the trade region level for movements between U.S. regions, Asia and Europe.

[25] Save the Cape, Inc. Panamax, Post-Panamax, and Sammax. A Primer on Ship Size.

The analysis was oriented towards examination of cargo density and arrival drafts. The results confirm the existence of weight and volume trades.

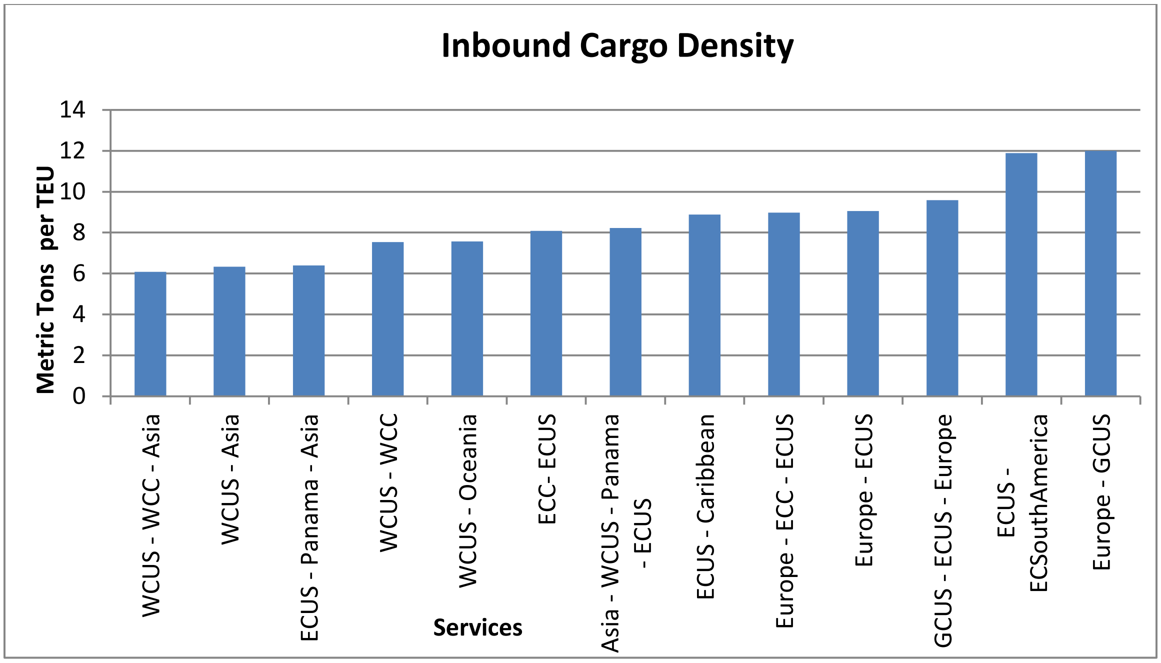
Figure 34 shows the average cargo density, in metric tons per TEU, based on WCSC data from 2006 through 2008, at a selection of U.S. ports. As can be seen from the figure, inbound cargo density is significantly lower at the West Coast ports, where traffic is primarily from Asia. This suggests that vessels arriving at these ports are volume limited, rather than weight limited.



Source: USACE Institute for Water Resources

Figure 34: Cargo Density at U.S. Ports

Using AIS data, it is possible to characterize vessel movements as being part of services, depending upon where they travel. As shown in Figure 35, there is a clear indication of volume and weight trades, based on inbound cargo density, with volume trade predominant on the West Cost – Asia services and weight trade predominant on East Coast / Gulf Coast – Europe services.



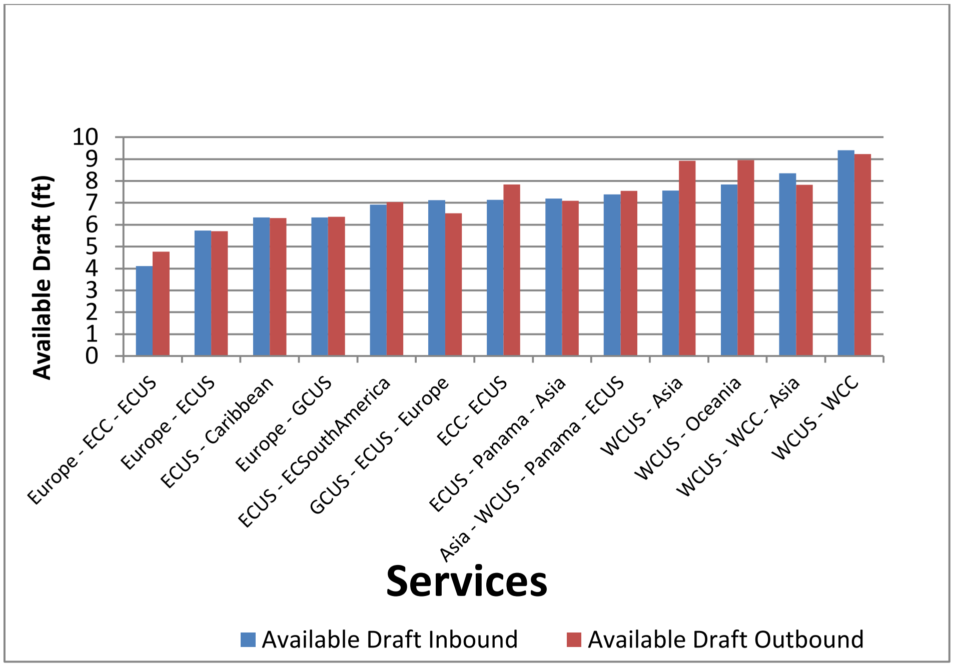
Source: USACE Institute for Water Resources

Figure 35: Average Cargo Density by Service

Trade regions in Figures 35 and 36 are abbreviated as follows:

- WCUS – West Coast United States
- WCC – West Coast Canada
- ECUS – East Coast United States
- ECC – East Coast Canada
- GCUS – Gulf Coast United States

In order to further explore the issue of weight vs. volume trades, the arrival and departure draft of the vessels making calls at U.S. ports for which services were identified was compared with the maximum draft of the particular vessel, leading to an "available draft," i.e. the maximum draft less the arrival or departure draft. This serves as an indication of the degree to which the particular vessel is utilizing all of its draft. As can be seen from Figure 36, services for U.S. East Coast ports tend to have lower available draft on arrival and departure than do services using West Coast ports. The increased available outbound draft for West Coast ports is likely due to returning empty boxes. WCSC data does not provide information on shipment of empties, so this cannot be verified through the currently available data, but is consistent with expectations.



Source: USACE Institute for Water Resources

Figure 36: Available Draft (maximum design draft less average sailing draft) by Service

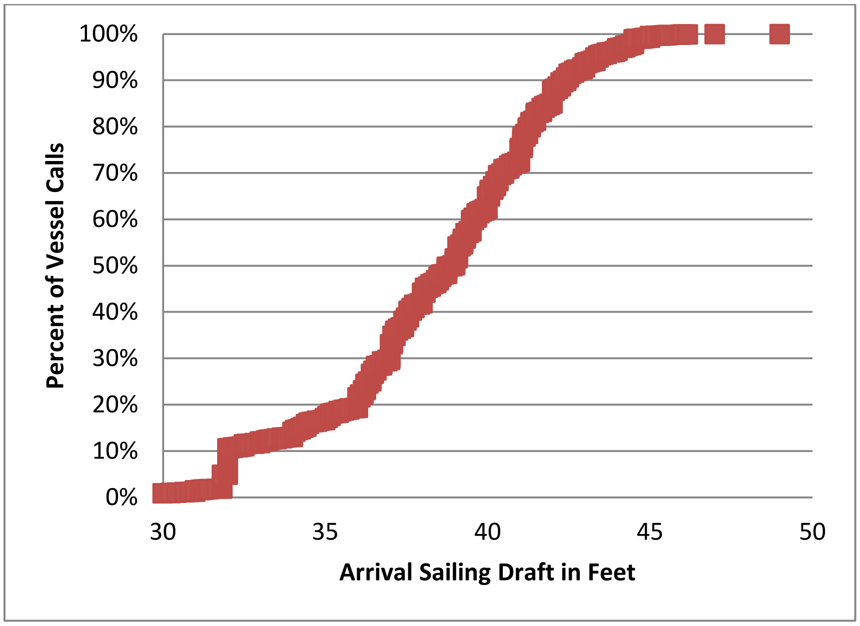
Examining direct trade between U.S. ports and Europe and Asia, using WCSC data, as shown in Table 9, the inbound cargo density is lowest for the West Coast – Asia trade, highest for the East Coast – Europe Trade. Deployment of the largest vessels on the West Coast - Asia Trade is also seen.

Table 9: Cargo Density and Available Draft By Trade Region, WCSC Data

Number of Calls	Vessel Class	Average Cargo Density (tonnes/TEU)	Average Available Draft (ft)	U.S. Port Trade Region	Foreign Port Trade Region
1483	Post-Panamax Generation 2	5.76	8.54	West Coast North America	Asia
268	Post-Panamax Generation 1	6.02	8.25	U.S. Atlantic	Asia
3383	Post-Panamax Generation 1	6.11	8.09	West Coast North America	Asia
3019	Panamax	6.16	6.25	West Coast North America	Asia
1093	Panamax	6.23	6.1	U.S. Atlantic	Asia
743	Sub-Panamax	6.46	3	West Coast North America	Asia
410	Post-Panamax Generation 1	8.48	7.35	U.S. Atlantic	Europe
1947	Panamax	9.07	4.71	U.S. Atlantic	Europe
1191	Sub-Panamax	9.39	2.86	U.S. Atlantic	Europe

Source: USACE Institute for Water Resources

To illustrate the importance of cargo density to sailing draft, Figure 37 shows the arrival draft for 2,479 *post-Panamax* vessel calls at the San Pedro Bay ports from 2006 through 2008. Only 12 vessel calls recorded an arrival draft of greater than 45 feet in the WCSC data.



Source: USACE Institute for Water Resources, Waterborne Commerce Statistics Center

Figure 37: Arrival Drafts of *post-Panamax* Vessels at LA/LB from Asia

Analysis of both the WCSC and AIS data sets clearly shows the existence of weight and volume trades, with vessels arriving at the West Coast of the U.S. from Asia at lower cargo densities than vessels arriving on the East Coast from Europe. Vessels arriving from Asia to the West Coast show greater available draft, most likely due to the lower cargo density.

Inland Waterways

USACE supports the safe, reliable, efficient, and environmentally sustainable movement of vessels on 12,000 miles of inland and intracoastal waterways. The waterways are the primary artery for half of the nation's grain and oilseed exports, 20 percent of coal for utility plants, and 22 percent of domestic petroleum movements.[26] USACE's role includes maintaining the 191 commercially active lock sites with 238 chambers that allow tows to "stair-step" through the nation's heartland.

This Center Gulf region, served by the Mississippi River and its navigable tributaries, could be a beneficiary of an expanded Panama Canal for exports. The Lower Mississippi is currently maintained to a depth of 45 feet. A 50-foot deep Panama Canal will allow current *Panamax* vessels transiting the Canal to be loaded to their full draft of 42 feet to 45 feet, a significant improvement over the current 39.5 feet. For the vessels with a 45 foot draft leaving New

[26] Grier, David. USACE Institute for Water Resources, The Declining Reliability of the U.S. Inland Waterway System.

Orleans at 39.5 feet heading for Asia, transportation cost saving gained by loading to 45 feet will be about $0.05 per bushel.

USACE completed the UMR-IWW System Navigation Feasibility Study in December 2004. In 2008, the *Re-evaluation of the Recommended Plan: UMR-IWW System Navigation Study – Interim Report*, a re-evaluation of the feasibility report recommended plan, was completed. Economic models of the river system were developed as part of this study and were used to assess the ability of the current system to handle potential increases in river traffic resulting from shift of mode benefits to Asia.

Informa Economics, Inc. estimates that the larger, more efficient *Cape* class ships reduce the cost of the movement of grains to northeast Asia by an all-water Panama Canal route by $0.31 to $0.35 per bushel of grain.[27] Assuming the Informa grain forecast and the re-evaluation report non-grain forecasts (163 million short tons in 2020), not all potential demand could be accommodated in 2020 with the current system infrastructure. However, using the alternative analysis assuming the Informa grain forecast and no growth in non-grain (87 million short tons), all potential traffic could be accommodated without waterway infrastructure efficiency improvements.

Beyond the sensitivity to non-grain traffic growth, several points regarding the accommodated/ unaccommodated traffic conclusions should be emphasized: (1) The time horizon for these conclusions is 2020. With additional traffic growth beyond 2020 there would be a greater magnitude of unaccommodated traffic (in the case of Informa grain and re-evaluation report non-grain), or an eventual state where at least some traffic would no longer be accommodated (in the case of Informa grain and no growth in non-grain). (2) The only constraint to traffic accommodation that has been considered is inland waterway infrastructure. In particular, landside infrastructure and deep-water port infrastructure have not been addressed in making inland waterway accommodated/unaccommodated traffic conclusions. (3) The determination that traffic can be accommodated in the future does not mean that it will be accommodated at existing cost levels. Given the willingness to pay for water transportation, some increases in cost can be incurred before shippers make the decision to no longer use the waterway. Any increase in traffic over the lock and dam portion of the system will result in additional congestion and cost. (4) The implementation timeframe for the subset of authorized UMR-IWW improvements that is sufficient to address improved waterway efficiency and "capacity" from a system perspective is no earlier than the mid 2020s.

Summary

The deployment of *post-Panamax* vessels will have impacts throughout the Nation's freight transportation system. To prepare for these vessels, ports will seek to widen and/or deepen

[27] Panama Canal Expansion: Impact on U.S. Agriculture, Informa Economics, September 2011. Note: This estimate of transportation cost savings assumes a Cape class vessel.

their channels and turning basins. Whether the port is preparing to be *post-Panamax* ready or cascade ready will depend on the specific needs and opportunities of the individual port. An analysis of population and trade growth, coupled with a survey of current port capacities, has shown the Nation's most critical needs are along the Southeast and Gulf Coasts.

The export of agricultural and other bulk commodities depends on the inland waterways. A comparison of the current system capacity with forecast increases in agricultural exports indicates adequate capacity through 2020 and possibly beyond. To take advantage of these export opportunities will require the maintenance of inland waterway capacity that serves these exports. The impact of *post-Panamax* vessels is not anticipated to necessitate the expansion of inland waterway locks.

Chapter 4: Environmental Impacts of Capacity Expansion

Chapter Purpose and Approach

The purpose of this chapter is to describe the existing environmental footprint of ports, waterways, and intermodal links to inform future possibilities and then compare modernization impact possibilities in regions of the United States that are most likely to be adversely impacted.

Potential environmental impacts and mitigation needs are important aspects of planning for port and waterway modernization in response to increasing international freight transport, intermodal container-based shipment in larger oceanic vessels, and Panama Canal enlargement. Although much investigation of modernization needs has transpired, as attested to in previous chapters, the environmental impacts have received much less attention. Mitigation costs can be substantial. At the Port of Savannah, for example, mitigation costs are about 45 percent of the total estimated harbor expansion cost.[28] Environmental rules and permit requirements have become more stringent as their benefits became clearer. Emphasis on effective environmental impact mitigation is expected to continue, if not increase, and to be an essential consideration in determining modernization costs and net benefits.

Possible adverse environmental impacts are based on indicators of potential impact sources and vulnerabilities of human populations and natural and cultural resources. Consistent with environmental goals established in the National Environmental Policy Act (NEPA), the vulnerability metrics were selected to indicate potential impacts on public health and safety (including the social inequity of many impacts), the sustainability of important resource heritage, and environmental services that support commercial, recreational, and other uses of natural marine, estuarine, freshwater and shore resources. The impact-source metrics indicate regional rates of freight transport growth based on regional population growth over the next three decades, the unused capacity of ports compared to percent growth in regional population, harbor expansion needs for acceptance of the largest *post-Panamax* vessels, and possible effects of Panama Canal enlargement. While specific port and waterway environmental assessments and impact statements were consulted, they were not uniformly available or comparable across regions. The Indicators were selected based on their national comparability across regional ports, reliability (mostly Federal databases), and representativeness. More detailed information can be found in a supporting IWR report.[29]

[28] Mayle, M. C. and M. Landers. 2012. Corps, GPA: Deepen river to 47 feet. Savannah, GA: Savannah Morning News, April 12, 2012.

[29] Cole, R. A., J. Y. Chung and S. B. Komlos 2012. The past environmental footprint and possible future environmental impact mitigation needs of port and waterway modernization in the United States.

The Environmental Footprint

Despite much improvement of impact mitigation since more stringent and comprehensive environmental laws were passed, the cumulative effects of adverse impacts from transportation system development and operations have left a significant environmental footprint. These impacts also interact with other sources of impact to degrade environmental quality. In the following subsections, the environmental footprint is first placed in perspective by geographic comparison to other sources of impact. Then the nature of past sources of the environmental footprint is summarized.

The Environmental Footprint

Much of the conterminous United States has been altered by land and water development and use. The change has been beneficial for the most part, but a large fraction of the Nation's natural environment has been replaced with substantially different qualities that have compromised important natural services in support of human welfare. About 13 percent of the conterminous United States is now reserved for light use in parks, wildlife refuges, and wilderness areas where most natural qualities prevail.[30] Another 56 percent is more intensively used for forest management, grazing and other use that sustains many natural qualities except where management is lax. Many natural qualities have been lost from the 27 percent used for intensive crop culture and rural residential development. The remaining 4 percent is densely urban or used for rural transportation. It includes the geographical area of landside port, highway and railroad impact, which is about 1.6 percent in total. Relatively few natural qualities remain in the footprint of these densely impacted areas.

Despite many benefits, human use and transformation of the landscape has come at significant environmental cost. It has cumulatively degraded some commercial and recreational use of resources.[31] It has contributed to health and safety concerns[32] and to probable or possible extinction of at least 240 American species, and the decline of many more.[33] While the freight transportation system has directly impacted a small percent of the total impacted area of the conterminous United States, the effects often are intense, extend well beyond directly impacted areas, and sometimes interact synergistically with other sources of adverse environmental impact.

The geographical impact of land and water use described above provides a high-altitude perspective that misses the growing scarcity of wetland and open-water environments, which are disproportionately impacted by ports and waterways. Wetlands have been reduced from

[30] Lubowski, R. N., M. Vesterby, S. Bucholtz, A. Baez, and M. J. Roberts. 2006. *Major Uses of Land in the United States, 2002/EIB-14* Economic Research Service/USDA, Washington D. C.

[31] Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Synthesis report. Island Press, Washington DC.

[32] Frumkin, H. Editor. 2010. Environmental health: From global to local. John Wiley & Sons, Inc. San Francisco, CA.

[33] Master, L. L., B. A. Stein, L. S. Kutner, and G. A. Hammerson. 2000. Vanishing Assets. Chapter 4 *In* B. A. Stein, L. S. Kutner, and J. S. Adams (Editors). Precious Heritage: The status of biodiversity in the United States. Oxford University Press, New York, NY

about 11.1 percent to about 5.3 percent.[34] During the past decade, tidal wetlands have been further reduced by the cumulative effects of rising sea level, channelization, sediment deprivation, other human impact, and hurricanes.[35] Now they are especially scarce, making up only 0.3 percent of the conterminous United States.

Open waters comprise 5.3 percent of the conterminous United States, including the American portion of the Great Lakes and coastal oceanic waters to the 12-mile territorial limit.[36] Without the Great Lakes and artificial reservoirs, the non-tidal inland waters of the conterminous U. S. amount to less than 1 percent of the total, much of that in lakes. The remaining free-flowing streams and rivers have become increasingly scarce and are now about 0.5 percent of the total area.[37]

Despite improvements in recent decades, freshwaters have been hit hard by physical, chemical and biological changes. Reservoir construction has increased the Nation's total open-water area in total while reducing the area of free-flowing water. Numerous non-native aquatic species are well established and some have costly effects.[38] Nearly 50 percent of streams and lakes remain unnaturally contaminated with nutrients, sediment, heavy metals and synthetic organic compounds.[39] As a consequence of these changes, about five times as many freshwater species as terrestrial species went extinct.[40] [41] Species extinction and imperilment is concentrated in areas with active ports and waterways, especially along the Pacific Coast, Southeastern Coast, and in states bordering the Ohio, Tennessee and Mississippi waterways.[42] [43]

Impacts of Transportation System Infrastructure

Development of highways, railroads and other land transportation infrastructure converted about 50,000 square miles (1.6 percent) of natural landscape to uninhabitable area for native species.[44] Freight transport has diverse environmental impacts.[45] Perhaps more damaging than

[34] Dahl, T. E., and G. J. Alford. 1996. History of Wetlands in the conterminous United States. Pages 19-26 In J.D. Fretwell, J. S. Williams and P. J. Redman (Editors). National water summary on wetland resources. U. S. Geological Survey Water Supply Paper 2425. Washington D. C.

[35] Dahl, T. E. 2012. Status and Trends of Wetlands in the Conterminous United States 2004 to 2009. U. S. Fish and Wildlife Service. Washington, DC

[36] U. S. Census Bureau. 2012a: Table 358. Land and water area of states and other entities, 2008. 2012 Statistical Abstract of the United States. Department of Commerce. Washington, DC

[37] See Cole et al. 2012 for documentation

[38] Pimentel, D., S. McNair, S. Janecka, J. Wightman, C. Simmonds, C. O'Connell, E.Wong, L. Russel, J. Zern, T. Aquino and T. Tsomondo. 2001. Economic and environmental threats of alien plant, animal and microbe invasions. Agriculture, Ecosystems and Environment 84:1-20.

[39] U.S. Environmental Protection Agency, U.S. Army Corps of Engineers. 2007. The Role of the Federal Standard in the Beneficial Use of Dredged Material from U.S. Army Corps of Engineers New and Maintenance Navigation Projects. EPA842-B-07-002. Office of Water, U.S. Environmental Protection Agency, Washington, DC 20460

[40] Ricciardi and Rasmussen 1999

[41] Cole, R. A. 2009. The sustainability of freshwater species and water resources policy in the United States. USACE Institute for Water Resources 09-R-9. U. S. Army Corps of Engineers, Alexandria, VA

[42] Master et al. 2000

[43] Stein, B. A., L. S. Kutner, G. A. Hammerson, L. L. Master, and L. E. Morse. State of the states. Chapter 5 *In* B. A. Stein, L. S. Kutner, and J. S. Adams (Editors). Precious Heritage: The status of biodiversity in the United States. Oxford University Press, New York, NY

[44] Lubowski et al 2006

lost area of natural habitat is the habitat fragmentation that contributes to declines of numerous terrestrial and semi-aquatic species.[46 47 48] Highways have greater impact than railroads because they cover more miles and a much greater area. Highways in particular alter hydrology and contribute to contaminated runoff.[49 50]

The geographical footprint of harbor and waterway infrastructure is much less than land-based transportation infrastructure. Over 926 harbors and 12,000 miles of waterways have been developed and are maintained by the U.S. Army Corps of Engineers.[51] The estimated total footprint is about 3,000 square miles. The estimate provides a basis for comparison despite uncertainty.[52] The estimated total geographical footprint is about 10 percent of the estimated 29,000 square miles of free-flowing rivers, natural lakes other than the Great Lakes, and estuarine wetlands, but many effects were temporary.[53]

Many lock and dam effects are permanent. The adverse effects of navigation reservoirs on species survival are well established.[54 55 56] Waterway impoundments cover about 500 square miles of natural river channel with deeper, slower water. Impoundment effects on river hydraulics are frequently cited as among the major factors contributing to the decline of riverine species, but especially freshwater mollusks.[57 58] Many of these species are protected under the ESA.

Another 7,000 miles of river and coastal shore was disturbed by excavation, dredged material disposal, and boat and barge use—about 400 square miles altogether. About 300 square miles of harbor channels were similarly disturbed. Annual maintenance dredging ranged up to 300

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[45] Hecht, J. 1997. The environmental effects of freight. Presented to the Joint Session of Trade and Environment Experts, Organisation for Economic Co-operation and Development. Paris, France http://www.oecd.org/dataoecd/14/3/2386636.pdf

[46] Fahrig, L., Pedlar, J. H., Pope, S. E., Taylor, P. D., and Wagner, J. F. 1995. Effect of road traffic on amphibian density. Biological Conservation 73:177-182.

[47] Forman, R. T. T., and Alexander, L. E. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

[48] Trombulak, S. C., and C. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14(1):18-30.

[49] Gjessing, E., E. Lygren, L. Berglind, T. Gulbrandsen, and R. Skanne. 1984. Effect of highway runoff on lake water quality. Science of the total environment 33:247-257.

[50] Jones, J.A., F.J. Swanson, B.C. Wemple and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14:76-85.

[51] USACE (U. S. Army Corps of Engineers). 2010. U. S. waterway system facts. Washington, DC http://www.ndc.iwr.usace.army.mil//factcard/fc02/factcard.htm

[52] see Cole et al. 2012 for methods

[53] Allen, K.O. and Hardy. J. W. 1980 Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review FWS/OBS-80/07. U.S. Department of the Interior, Fish and Wildlife Service. Washington, D.C.

[54] Neves, R. J., A. E. Bogan, J. D. Williams, S. A Ahlstedt,and P. W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. Pages 43-85 *in* G. W. Benz and D. E. Collins, eds. Aquatic fauna in peril: the Southeastern perspective. Special Publication 1, Southeastern Aquatic Research Institute, Lenz Design and Communications, Decatur, GA.

[55] Parmalee, P. W. and A. E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville, TN

[56] Cole 2009

[57] Parmalee and Bogen 1998, Neves et al. 1997

[58] Watters, G. T. 1999. Freshwater mussels and water quality: A review of the effects of hydrologic and instream habitat alterations. Pages 261-274, Proceedings of the First Freshwater Mollusk Conservation Society Symposium.

million cubic yards/year[59] since the waterways were virtually completed 40 years ago and averaged perhaps half of that rate during the time period most modern waterways were developed from 1930 to 1970. Deposited to a depth of 10 feet, material from maintenance dredging would cover about 1,800 square miles of aquatic and upland habitat. About 10 percent of the disposed dredged material was severely contaminated with toxic materials.[60] Environmental laws now require proper treatment and containment.

Numerous studies of dredging effects completed after NEPA and the Clean Water Act were passed were reviewed by Allen and Hardy.[61] In general, dredging temporarily reduced bottom organism abundance except in highly altered environments, such as contaminated sediment and deep channels where depressed productivity and altered species composition often persist. Sediment toxicity effects bottom organisms, fish and other predators and humans at the end of the food chain.[62] Deepening channels in estuaries can allow saline water to penetrate deeper into freshwater ecosystems where it may damage wetlands and contaminate water supplies.[63] [64] Rising sea level associated with global warming may worsen these effects. Dredging in some scarce ecosystems has had more persistent adverse effects on productivity and species composition, including unavoidable take of threatened and endangered species[65] in shallow estuary wetlands[66] and coral reefs. Dredging impacts on threatened and endangered species have improved significantly. Sea turtle take, for example, has been reduced to about 35 per year, which is a small fraction of total human-caused mortality. Past disposal on land created new habitat that could be more or less desirable than original habitat, depending on the site and its management. Islands created incidentally from dredged material disposal provided beneficial refuges for birds[67] before dredged material was intentionally used for that and other beneficial purposes.

Following institution of strong laws and executive orders, Corps policy in recent decades has emphasized protection of healthy wetlands and effective containment and treatment of contaminated sediments. In 1992, the Corps was authorized to beneficially use dredge material

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[59] Francingues Jr., N. R., M. R. Palermo, C. R. Lee, and R. K. Peddicord. 1985. Management strategy for disposal of dredged material: Contaminant testing and controls. Miscellaneous Paper D-85-1. U. S. Army Corps of Engineers, Engineer Research and Development Center. Vicksburg, MS.

[60] Francinques et al.1985

[61] Ibid.

[62] Burton, G. A. and P. F. Landrum. 2005. Toxicity of sediments. Pages 478-571 *In* G. V. Middleton, M. J. Church, M. Carigilo, L. A. Hardie, and F. J. Longstaff (Editors). Encyclopedia of sediments and sedimentary rocks. Springer-Verlag. New York, NY

[63] PIANC Working Group no. 6. 1993. Problems caused by saltwater infiltration. Appendix 3: Summary of saltwater intrusion problems due to inland navigation channels in the United States. Permanent International Association of Navigation Congresses. Brussels, Belgium

[64] Savannah District Corps of Engineers. 2011. Draft tier II environmental impact statement for the Savannah Harbor expansion: Chatham County, Georgia and Jasper County, South Carolina. U. S. Army Corps of Engineers. Savannah, GA

[65] U. S. Army Corps of Engineers. 2006. USACE sea turtle data warehouse. Washington, DC. http://el.erdc.usace.army.mil/seaturtles/intro.cfm

[66] Ray, G. L. 2007. Ecological Functions of Shallow, Unvegetated Estuarine Habitats and Potential Dredging Impacts (with emphasis on Chesapeake Bay). ERDC TN-WRAP-05-3. U. S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS.

[67] Landin, M. C. and R. F. Soots. 1978. Colonial bird use of dredged material islands: A national perspective. Proceedings of the Colonial Waterbird Group:Volume 1. Waterbird Society, Waco, TX http://www.jstor.org/stable/1520902

for environmental improvement. About 20 to 30 percent of dredged material is now being used beneficially.[68]

Impacts of Transportation System Operations

For many people, the transportation system impacts of greatest concern are the adverse effects of atmospheric emissions associated with fuel consumption, including greenhouse gas emissions. Fuel efficiency is an important consideration in seeking the most beneficial combination of transport modes, including atmospheric impacts. The land- and water-based freight transportation system consumes 8.6 percent of the total energy used.[69] While large ocean-going vessels in general are highly fuel efficient,[70] smaller vessels, such as those used for waterway barge transport, are substantially less so. Separate assessments by USDOF [71]and OEE[72] indicate that freight trains and smaller freight vessels have similar fuel efficiencies, but that trains and trucks have been improving while waterway vessels have not. Trucks consume over 72 percent of freight-transport energy used, largely because of fuel inefficiency.[73] Greenhouse gas emissions from the different transport modes exhibit similar ratios.[74] Reducing truck traffic in favor of train and barge is often promoted but difficult to accomplish. Trucks need to be used at points of freight origin and delivery and, despite higher fuel costs, are the most cost-effective mode for short freight hauls.[75]

Because property values are typically lower near sources of pollution, congestion, and unpleasant appearance, people with low income are more likely to be impacted. This inequitable impact is inconsistent with national environmental policy and recent presidential emphasis on executive order 12898 on environmental justice.

Among other effects of operations, vessel wakes contribute to shoreline erosion, including wetland and bottom community changes.[76] [77] [78] Vessel-caused turbulence also disturbs bottom communities and contributes to turbidity,[79] which deprives submerged plants and sight-feeding species of necessary light. However, this is a minor source of turbidity compared to nutrient enrichment and sediment runoff resulting from human caused changes in watersheds. Vessel,

[68] U.S. Environmental Protection Agency, U.S. Army Corps of Engineers. 2007

[69] U. S. Department of Engergy. 2012. Transportation energy data book. 30th Edition. http://cta.ornl.gov/data/index.shtml

[70] Economic Development Research Group, Inc. 2012. Panama Canal Expansion Study Phase 1 Report: Developments in Trade and National and Global Economies. *Prepared for:* The United States Department of Transportation, Maratime Administration. Washington, DC

[71] IBID

[72] OEE (Office of Energy Efficiency). 2011.   Energy use handbook tables (Canada). Natural Resources Canada. Ottawa, Ontario

[73] USDOF 2012

[74] OEE 2011

[75] Economic Development Research Group, Inc. 2012

[76] Koch, E. W. 2002. Impact of boat-generated waves on seagrass habitat. Journal of Coastal Research 37: 66-74

[77] Bishop, M. J. 2005a. Displacement of epifauna from seagrass blades by boat wake. Journal of Experimental Marine Biology and Ecology 354:111-118

[78] Bishop, M. J. 2005b. Joint effects of boat wake and dredge spoil disposal on sediments and assemblages of macro-invertebrates. Estuaries, 28: 510–518

[79] Allen and Hardy 1980

port, train and truck operations often are sources of oil, metals, and other water pollutants.[80] Vessel cargo and ballast water have been major vectors for non-native invasive species with adverse environmental effects.[81] [82] Trucks and trains are major means for nonnative species invasion of inland areas.[83] All modes contribute to inequitable exposure of low income and minority groups to unhealthy pollutants and noise.[84] Intermodal trucks contribute to vehicular traffic congestion. Ports have been addressing these problems, but according to critics can improve further.[85] [86]

Impacts of Accidents

Accidents not only threaten human safety and health, but scarce ecosystems and species as well. Accidents often receive attention disproportionate to their contribution to all transportation system impacts, but can be locally to regionally costly as signified by large oil spills, which are most associated with vessel collisions and pipeline breaks.[87] Accidents in and around ports are a function of increasing traffic rates and counteractive measures.[88] Vessel collision with endangered whales, sea turtles, fish and other species is a concern in a number of port areas.[89] [90] Recently imposed regulation of vessel speeds may reduce that source of mortality. Vehicular traffic is a threat to some endangered species.[91]

Future Environmental Impact Vulnerabilities and Possibilities

Given the uncertainty about where and what form and extent transport system modernization actually takes place, regional forecasts of adverse impact and mitigation needs are uncertain. Other environmental and social changes only amplify that uncertainty, including the potential effects of sea level change on *post-Panamax* depth requirements and associated adverse impacts. Instead of specific forecasts, indicators of human and resource vulnerabilities and possible sources of adverse impacts were used to discuss regional differences and similarities.

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[80] Bailey, D., T. Plenys, G. M. Solomon, T. R. Campbell, G. R. Feuer, J. Masters, and B. Tonkonogy. 2004. Harboring pollution: The Dirty Truth about U.S. Ports. Natural Resources Defense Council, Washington DC

[81] NRC (National Academies of Science) 1996**.** Stemming the tide. Controlling introductions of nonindigenous species by ships' ballast water. National Academies of Science. Washington DC

[82] Corn, M. L., E H. Buck, J. Rawson, A. Segarra, and E.Fischer. 2002. *Invasive Non-Native Species: Background and Issues for Congress.* CRS Report RL30123 Congressional Research Service, Washington, DC

[83] Greenberg, D.H., S.H. Crownover, and D.R. Gordon. 1997. Roadside soil: a corridor for invasion of xeric scrub by nonindigenous plants. Natural Areas Journal 17:99-109.

[84] Rhodes, E. L. 2003. Environmental Justice in America. Indiana University Press: Bloomington, IN

[85] Bailey et al. 2012

[86] Cannon, J. S. Undated. U.S. Container Ports and Air Pollution: A Perfect Storm. Energy Futures, Boulder, CO http://s3.amazonaws.com/energy-futures.com/port_study_ef.pdf

[87] Etkin, D.S. 2001. Analysis of oil spill trends in the United States and worldwide. *Proceedings,* 2001 International Oil Spill Conference*.* American Petroleum Institute, Washington, DC.

[88] Etkin 2001

[89] Vanderlann, A. S. M. and C. T. Taggart. 2006. Vessel collisions with whales: The probability of lethal injury based on vessel speed. Marine Mammal Science 23:144-156.

[90] Laist, D. W. and C. Shaw. 2006. Preliminary evidence that boat speed restrictions reduce deaths of Florida manatees. Marine Science 22:472-479.

[91] Fahrig et al. 1995

Environmental assessments and environmental impact statements for individual actions were consulted, but varied greatly in coverage and were difficult to compare directly across regions. Eleven quantified indicators of environmental vulnerability and sources of modernization impact were used. The indicators were selected based on environmental impact history data, comparability across regions, quantification, reliability and representativeness. All data were gathered by authorized Federal agencies.

Potential Environmental Impacts at Ports

The indicators of the potential regional impact of future modernization and need for mitigation are shown in Table 10 with footnotes about each metric used. The metrics indicate environmental vulnerabilities in the vicinity of port locations. They include vulnerabilities of human populations (air emission fractions, water discharge permits, superfund sites, and low income and minority groups), cultural and natural resources of important heritage value (official reserves, wetlands, and endangered species), and beneficial uses of natural resources (commercial fishing, sport fishing and public beach area). Cole et al. (2012) describe the indicator metrics in detail. Three other general metrics were used to indicate the potential for significant environmental impacts of modernization on vulnerable people and resources. These include potential impact from harbor expansion, increased operations associated with greater freight movement, and port expansion to increase capacity. The modernization impact metrics indicate general sources of impact while the vulnerability metrics indicate the relative significance of the populations and resources that may be impacted.

Port harbors vary in their readiness to accept *post-Panamax* vessels and increased freight traffic. A fully ready harbor is assumed to allow any vessel to call once it has passed through the new Panama Canal locks, which will have 50-foot depths upon completion. The difference between 50 feet and existing depth times the main channel length is used as an indicator of harbor expansion impact. Landside port expansion needs and associated infrastructural and operations impacts are indicated by the differences between the average unused port capacity and projected 30-year regional population growth rates, both expressed as percentages. In general, less port modernization is needed where unused capacity exceeds forecast population growth by significant amounts. However, modernization for the largest *post-Panamax* vessels may require changes in freight transfer equipment and berth dimensions. The 30-year growth of the region served by the ports indicates environmental impacts associated with freight transport growth and associated operations effects, such as from pollution emissions and accident frequency. These impacts could be moderated by transporting the freight on fewer but larger vessels.

Table 10. Regional Indication of Potential Environmental Impact for the Four Most Important Container-port Regions. The raw data for individual metrics were normalized to values between 0 and 100 to allow regional comparison and summation.

Indicators	Port Regions[1]			
	Northeast Atlantic	Southeast Atlantic	Gulf	Pacific
Vulnerabilities				
Health, Safety & Equity[2]	44.2[8]	35.7	45.7	48.9
Heritage Loss[3]	11.9	33.7	26.2	20.3
Economic Loss[4]	27.7	25.9	22.1	34.0
Subtotal	83.8	95.3	94.0	103.2
Modernization Sources				
Harbor Expansion[5]	33.2	16.6	29.8	0
Freight Transport[6]	17.8	73.7	43.3	76.0
Port Expansion [7]	44.0	90.6	60.2	74.6
Subtotal	128.0	180.9	133.3	150.6
Total	211.8	276.2	227.3	253.8

1. Port selection was based on main channel depth and freight volume. The Northeast Atlantic includes Boston, New York-New Jersey, Philadelphia, Wilmington, and Baltimore. The Southeast Atlantic includes Norfolk, Wilmington, Charleston, Savannah, Jacksonville, Port Everglades and Miami. The Gulf includes Tampa, Mobile, New Orleans, and Houston. The Pacific region includes Los Angeles, Long Beach, Oakland, and Tacoma.
2. Health and safety vulnerabilities are indicated for an area within 10 km of ports by 1) number of days air pollution exceeded limits for respiratory illness, 2) number of permitted waste water discharges, and 3) number of superfund sites (EPA 2012 a and 2012b). Potential for environmental injustice is indicated by the percentages below poverty level and in non-white minority groups within 5 km of the port. (Census Bureau (United States Census Bureau). 2011. 2010 public use microdata areas (PUMAs). Department of Commerce, Washington DC http://www.census.gov/geo/puma/puma2010.html)
3. Vulnerability to loss of important local and national heritage is indicated for an area within 10 km of the port by 1) the percentage of wetlands. (USGS (United States Geological Survey) 2010.) National land cover database. (U.S. Department of the Interior. Washington DC http://www.mrlc.gov/index.php); 2) the area encompassed in parks and other preserves. (USGS (United States Geological Survey) 2012). USGS gap analysis program. (U.S. Department of the Interior. Washington DC http://gapanalysis.usgs.gov/data/padus-data/); and 3) the number of species listed as threatened or endangered (FWS 2012).
4. Vulnerability to a loss of natural resource economic value is indicated by 1) the state commercial fish dockside value divided by state shoreline length (NOAA 2012). Annual commercial landings by Group (year 2010). NOAA Fisheries, National Oceanographic and Atmospheric Administration. Washington, DC http://www.st.nmfs.noaa.gov/st1/commercial/landings/gc_runc.html) and Census Bureau 2012a, 2) state saltwater fishing days divided by state shoreline length (FWS, (U. S. Fish and Wildlife Service and the U.S. Department of Commerce, and U.S. Census Bureau) 2006. National Survey of Fishing, Hunting, and Wildlife-Associated recreation. FHW/06-NAT. U. S. Department of Interior. Washington, DC**)** and (Census Bureau 2012a), and 3) area of public beaches within 10 km of the port (EPA (United States Environmental Protection Agency). 2012c. Watershed assessment, tracking & environmental results. USEPA. Washington, DC http://www.epa.gov/waters/data/downloads.html#BEACH Datasets (EPA BEACHES dataset)). State data were divided by shoreline length to account for large differences in the dispersal of fishing access along shore and away from ports.

5. Harbor channel expansion needed to accept the largest post-Panamax vessels is indicated by the difference between existing depth and 50 feet times existing channel lengths. This metric indirectly indicates potential excavation and maintenance impacts.
6. Future rate of freight transport through ports is indicated by the 30-year population growth in states within 500 miles of the port. This metric indirectly indicates possible impacts from emissions and other operations effects.
7. Port expansion needs and potential impacts are indicated by the differences between percentage population growth over the next 30 years and the mean percentage of unused capacity for 1) berth size for vessels calling at the ports, 2) number of berths serving calling vessels, 3) freight transfer cranes, 4) port storage space, and 5) average vessel utilization.

Total vulnerability scores were slightly lower than average in the Northeast largely because of low heritage impacts associated with endangered species and preserves. The Pacific Region vulnerability was higher than average because of greater potential health and economic impacts. The sum of vulnerability differences among regions is smaller than differences in potential need for modernization and its associated environmental impacts. No region was consistently more or less vulnerable across all indicators. This suggests that modernization is likely to incur significant costs for required environmental impact avoidance, minimization, and compensatory mitigation, regardless of the region modernized. However, mitigation cost would vary widely among ports within regions depending on their specific vulnerabilities and impact extents and intensities.

Potential modernization and freight transport impacts are especially high in the Southeast and Pacific regions where regional population growth is nearly equally high and port capacities are most used. The higher score of the southeastern region is due largely to less harbor and port capacity The harbors at two major ports in the Northeast are, or soon will be, ready for *post-Panamax* vessel use, but the amount of dredging required at ports that are not ready makes potential harbor expansion impacts the highest among regions. However, actual population growth and percent growth is quite low in the Northeast compared to the other regions, making future modernization needs the lowest. The Gulf Region has a somewhat less unused capacity and more anticipated regional growth, but substantially less than in the southeastern and Pacific regions.

When vulnerability and potential modernization scores are totaled, the Southeastern region is highest and the Pacific region a close second. Metric scores are not likely to be proportional to mitigation costs, however. The Northeast Region ranks lowest. The physical need for harbor expansion in the Southeast Region is low compared to other regions, for example, but heritage vulnerability to harbor expansion impact is comparatively high.

While the impacts of harbor expansion could be substantial, there are potential environmental benefits from increasing capacity for *post-Panamax* vessels if, as expected, it moderates impacts on air and water quality impact per ton of freight shipped. Assuming that freight transport rates will increase regardless of average vessel size calling at the ports, harbor expansion could reduce anticipated increases in emission impacts on human health, including inequities among minority and low income groups near the ports. Other effects are harder to judge. While the frequency of ship passages may decrease, possibly lowering the number of harmful collisions with scarce species and other costly accidents, the increased size of the vessels may increase the likelihood of collisions when a vessel passes through the area. Regulations to slow vessel speeds may moderate any difference in potential effect. Accidents involving freight losses and oil and other spills may be more costly on larger vessels because more freight is lost and more harmful pollutants are released.

The results of analysis shown in Table 10 could be significantly altered by the effects of Panama Canal expansion, which may reduce the transport costs of freight with eastern destinations that now enter through Pacific ports. Panama Canal enlargement could result in a significant shift in transport-cost advantages at Southeastern ports, especially if they are able to accept *post-Panamax* vessels. That could also reduce transport system atmospheric emissions because of the higher fuel efficiencies of large vessels. If the scenario plays out, freight transport rates through southeastern ports could be elevated above the rates indicated by forecasts of future population growth in the southeastern region. Highway and rail transport from southeastern ports into areas in the U. S. interior now served by Pacific ports may somewhat reduce projected freight movement through Pacific ports based on regional population growth alone. That prospect could redistribute the intensity of adverse emissions impacts from west to east and further support harbor enlargements with their associated potential impacts on valued resources.

Another possibility could alter the picture. Existing *post-Panamax* ports on the East Coast and international ports in the Caribbean have potential for becoming deepwater transport hubs for vessels of all sizes. That may favor smaller feeder vessel delivery of transferred freight to East Coast ports that are not ready for *post-Panamax* vessels.[92] If that happened, freight transport rates and pollutant emissions may increase above regional population predictions, but the environmental impacts from harbor expansion may be largely avoided. Atmospheric emissions from vessels would increase because emissions, per ton of freight transported increases as vessel size decreases.[93]

Improved performance of rail and highway freight transport from West Coast ports could also moderate a Panama Canal effect. Pacific ports are better prepared than eastern and Gulf ports to accept *post-Panamax* vessel sizes and container traffic, have transport-time advantages, are projected to serve rapidly growing populations west of the Appalachians, and may become more competitive by cutting their costs.[94] Such advantages could result in relatively little change in the proportion of freight moving into east and west ports despite Panama Canal enlargement. Cost cutting strategies like container stacking on railroad cars and increased truck-trailer lengths could significantly reduce the growth in atmospheric emissions per ton of freight transported, but perhaps not enough to make up for the much greater efficiency of large vessels entering the eastern U.S. through East Coast ports. The tradeoffs among different scenarios are complicated by numerous unknowns and by harbor enlargement impacts at

[92] Economic Development Research Group, Inc. 2012
[93] Notteboom, T.E. and B Vernimmen. 2009. The effect of high fuel costs on liner service configuration in container shipping. Journal of Transportation Geography 17:325-337.
[94] Economic Development Research Group, Inc. 2012

Southeastern ports and local air quality degradation and port congestion at some West Coast ports that are already stressed.

Regional summaries do not reveal the substantial variation in vulnerability and modernization need that occurs among sites within each region. The results indicated in Table 6 are preliminary, given the variation in the data, incomplete representativeness of the impacts, and uncertainty in various national and world transportation decisions. But the results are of strategic interest because they reinforce the uncertainties that signal a need for an adaptive approach to port and waterway modernization investment and "flag" potential impacts for specific attention in future environmental impact studies.

Potential Environmental Impacts at Waterway Locks

Panama Canal enlargement may make shipment of grains and other goods out of the Midwest to Gulf ports and Asian markets more attractive than existing routes. That could increase barge traffic down the upper Mississippi and Illinois Rivers and on to the Gulf. Potential environmental impacts are most associated with lock rehabilitation to maintain reliability.

Lock rehabilitation would largely occur in areas of relatively low human population density where health and safety concerns are relevant but less likely to affect people to the extent probable around ports. Atmospheric emissions would increase as barge and intermodal transport increased, but maintaining lock reliability through rehabilitation would moderate the increase by reducing barge congestion in the lock vicinity. The main alternative to barge transport is rail or truck transport directly to Gulf ports, which would circumvent the need for a shipment transfer. Barge shipment no longer has an environmental advantage over railroads because railroads are now about equally efficient.[95] Truck transport remains more versatile, but much less fuel efficient.

The upper Mississippi and Illinois rivers are home to a number of freshwater mussels and other threatened and endangered species, but, in general, adverse impacts on them are likely to be small. Our analysis indicates that 62 percent of the 100 meter riparian strip next to locks and dams on the upper Mississippi is wetland based on data from FWS,[96] which would require compensatory mitigation. On the Illinois River, 42 percent is wetland. No critical habitat of endangered species is expected to be impacted, but at least 1 endangered riparian species lives in each of the counties where most locks are located. The resource uses most likely to be impacted are agricultural and residential.

Summary

[95] USDOF. 2012. OEE 2011

[96] U. S. Fish and Wildlife Service. 2012. Environmental Conservation Online System. U. S. Department of the Interior. Washington DC http://ecos.fws.gov/ecos/indexPublic.do

A small area of the conterminous United States has been transformed by the land and water transportation system, but the adverse impacts on humans, ecosystems and wild species are significant despite major improvements in mitigating impacts. The environmental footprint of the transportation system indicates that future environmental impact from transportation system modernization could be associated with degraded human health and safety (including inequitable impacts on low income and minority groups), loss of important natural and cultural heritage, and loss of economically important natural resources. Impacts could come from changes in air and water quality, harbor and port expansion, and intermodal links. A regional assessment of potential impact sources and human population and resource vulnerabilities reveals the potential for somewhat greater environmental impact in the Southeast Atlantic and Pacific Regions, largely because these are the areas where freight transport growth is expected to be greatest. The effects of Panama Canal expansion have potential to redistribute some freight transport growth from Pacific ports to Southeast Atlantic ports. Adverse impacts from possible lock rehabilitation in the Upper Mississippi and Illinois Rivers are expected to be relatively minor except for potential need to mitigate for loss of riparian wetlands. In general, the uncertainties point to the need for an adaptive approach to future investment in port and waterway modernization. In that approach, port and waterway use would be monitored and modernized systematically as more certain information about freight movement, environmental impacts, and public benefits becomes available.

> "Factoring in environmental and public health costs needs to be part of the decision making process at every step in order to ensure future sustainability of our ports, our coastline, and our population."
>
> -Environmental Defense Fund

Chapter 5: Financing Options for Funding U.S. Port and Inland Waterway Infrastructure Needs

To remain competitive in a changing global trade market, the U.S. would need to continue making the justified investments necessary to maintain and improve its navigation transportation infrastructure, where it is appropriate and efficient to do so. Understanding the current funding challenges and making long-term plans for operations and maintenance (O&M) and justified investments are critical to developing an effective vision for a competitive navigation system.

USACE Civil Works appropriations to address waterside infrastructure has averaged about $1.5 to $2 billion per year for the last decade. These expenditures have been used to maintain, construct and improve the most highly justified inland and coastal navigation infrastructure projects, and reflect the Nation's most efficient navigation investment strategy.

To accommodate expected increase in agricultural exports through the Gulf, the current inland waterways must be adequately maintained through maintenance dredging and justified major rehabilitation.

USACE currently has 17 active studies investigating possible port improvements, most associated with the desire to be *post-Panamax* ready. One such study at the Port of Savannah is nearing completion and indicates an economically justified project that will cost about $652 million. It is likely that other studies will also show economically justified projects, either to become "*post-Panamax* ready" or "cascade ready." The preliminary estimate to expand some ports along these two coasts was about $3 to $5 billion. Specific investments in ports must be individually evaluated for their timing and economic and environmental merits.

Addressing "the critical need for additional port and inland waterway modernization to accommodate *post-Panamax* vessels" necessitates an examination of the current delivery mechanisms, the identification of issues and the offering of options for the future. Among the issues identified, securing funding sources to take advantage of modernization opportunities in a timely manner, given the constrained fiscal environment, was judged the most critical. A notional list of financing options is presented to initiate discussion of possible paths to meet this challenge—it is anticipated that a variety of options may be desirable, and in all cases individual project characteristics, including its economic merits, would need to be considered in selecting the optimal financing mechanisms. These options are illustrative only and do not necessarily represent any Administration, USACE or IWR position.

The Administration and Congress divide the U.S. Army Corps of Engineers budget into the broad categories of construction (which may include major rehabilitation) and operations, maintenance, repair, rehabilitation and replacement (O&M). For every dollar spent by USACE for harbor improvements (channel deepening and widening) a certain percent is appropriated from general Federal revenues. The cost share, which varies by depth of the harbor, is paid by project sponsors, typically port authorities or states, over a 30-year period.[97] All harbor maintenance dredging up to 45 feet is paid with appropriations from the Harbor Maintenance Trust Fund (HMTF). Over 45 feet, there is a 50 percent non-Federal cost-share requirement.

The USACE budget for inland waterways improvements (construction) draws from the balance in the Inland Waterways Trust Fund (IWTF) for 50 percent of each appropriated dollar and general Federal revenues for the other 50 percent. Operations, maintenance and repair to the inland waterway channels and navigation locks and dams are funded entirely by general Federal revenues. (See Vocabulary of terms used in this chapter on page 88.)

There is a long-standing Federal funding commitment, manifested through the USACE budget, to harbor improvement and maintenance and inland waterway navigation system improvement and O&M. In recent decades some of this financial responsibility has been transferred to the beneficiaries of the projects in the form of increases in required cost share and as requirements to pay user fees and dedicated taxes into the two trust funds. Attention is now directed to whether Federal general revenue and trust fund appropriations are adequate to improve, operate and maintain inland waterways and assure that Gulf and East Coast harbors have the channel capacity to accommodate larger ships that will soon pass through an expanded Panama Canal.

The budgetary concern is for improvements to and maintenance of existing harbors and inland waterways and is not about the creation of "new" ports, channels, navigation locks or dams. The concern is over how the Nation can secure and then efficiently spend funds that will secure the future value of past valuable investments. Because of the historical role played by the Federal government through USACE, an associated question becomes "What is the role for USACE in assuring that future value?"

In recent decades USACE responsibilities have expanded to include environmental oversight and regulation of environmental impacts associated with improvements and O&M at harbors and on the inland waterway navigation system. Such improvements and O&M alter the geomorphic and hydrologic processes in coastal estuaries and along rivers and, in turn, habitat conditions and aquatic life. Other environmental concerns associated with this transportation system include finding acceptable means for disposal of contaminated dredged material, the disposal of ballast water and, as appropriate, the beneficial use of clean dredged material for habitat creation. (See Chapter 4 for discussion of environmental effects).

As part of its project evaluation of proposed improvements and O&M, USACE evaluates environmental impacts and determines how to avoid and minimize such impacts.[98] Where avoidance and minimization is not possible, the project budget includes funds that provide for

[97] Non-Federal cost share requirements are as follows: Harbor Depth less than 20 feet: 20%; Harbor Depth 20-45 feet: 35%; and, Harbor Depth > 45 feet: 60%
[98] These evaluations are made in compliance with the National Environmental Policy Act as well as other Federal or state government required assessments.

compensatory mitigation. The costs for compensatory mitigation can be a substantial part of the total costs of any improvement project. For example, about 45 percent of the total cost of the proposed channel deepening for Savannah harbor to 47 feet is for the mitigation requirements established within the USACE planning process. Even still, there have been challenges to the plan that assert that the mitigation is inadequate or even that the project should be abandoned because it has unacceptable environmental consequences.

Vocabulary

General Revenue Funding – Appropriations for the cost of construction, operations, maintenance and repair of harbors and waterways made from general revenues of Federal and non-Federal governments.

Beneficiary Based Funding – Payments for the cost of construction, operation, maintenance and repair of harbors, channels, locks and dams using revenues from user fees or from a dedicated tax source. A user fee is a charge paid voluntarily by the user of the harbor or waterway; failure to pay the charge results in exclusion from use (e.g., a lock passage fee or a wharf access fee). In contrast, a dedicated tax is a required payment to a government entity, enforced by threats of sanction for nonpayment rather than by denial of a use (e.g., a tax on fuel). Revenues from user fees and dedicated taxes are often deposited to a government managed trust fund.

Trust Fund – A government established and managed account that accumulates the revenues from user fees and dedicated taxes. The managers of the fund make decisions about the disbursements from the fund.

Cost Sharing – A legally mandated sharing of the costs for construction, operations, maintenance and repair for harbor and waterway improvements and OMR between the Federal government and a non-Federal entity. Cost-sharing is a requirement for Federal budgetary participation in harbor and inland waterway improvements.

Cost Recovery – A requirement that all costs for construction, operation, maintenance and repair costs incurred over a period of time be matched by general tax revenues and receipts from user fees and dedicated taxes. Since benefits are realized over time, payments toward cost recovery may be received over several years. Upfront costs will typically require sale of bonds; repayment of bond debt would be spread over some period of project life.

Financing – The advancement of funds from a public, quasi-public or private entity to an entity initially responsible for the costs of improvements and OMR at harbor and waterway facilities. The responsible entity then uses a combination of general revenues, user fees and dedicated taxes to repay the incurred debt.

Infrastructure Bank – A chartered government institution that makes or guarantees loans for non-Federal infrastructure improvements in anticipation of repayment through future dedicated revenue streams, such as revenues from user fees or dedicated taxes.

Under the Clean Water Act the USACE regulatory program has responsibility, shared with the U.S. Environmental Protection Agency, to issue permits for the placement of fill material in U.S. waters. In reviewing these permits the regulatory program is obligated to be sure that the proposed action is needed, minimizes adverse environmental effects and then compensates through mitigation for any unavoidable adverse environmental consequences. In current planning and budgeting practice, USACE harbor and navigation business lines have the lead in planning for and implementing improvements and O&M and the regulatory program issues a permit if it affirms the environmental assessment and mitigation of the USACE planning process. Also, the 404 permit process requires that the states affirm the compatibility of any improvement or maintenance operation with state water quality standards, consistency with Coastal Zone Management Act plans if appropriate, and other environmental laws and regulations of both the state and Federal government.[99] Therefore, even if a non-Federal entity wishes to deepen a harbor (for example) with its own funds, USACE would still be involved in issuing the appropriate environmental permits. [100]

Harbor Funding (Maintenance and Construction)

Decisions on spending HMTF dollars for maintenance dredging are made through a hierarchical process that begins with requests made at the USACE district level and ends with allocations made in the President's budget. Modest adjustments have been made in the past during the congressional appropriations process.[101] Allocations made from the HMTF during the past five years have been less than the revenues earned; there is a balance in the HMTF account.

The principal concern regarding harbor maintenance is whether the level of collections and disbursements from the HMTF will be adequate to maintain harbors at levels sufficient [102] to provide reliable service to shippers. Looking forward, the question is whether revenues collected with the current HMTF fee system can keep pace with increasing costs of dredging over time even if all collected funds were allocated to maintenance (possible causes of increasing costs include increased shoaling, increases in unit costs of dredging).

[99] These requirements can be far-reaching and, for example, can extend to the evaluation of effects on local and regional air quality.

[100] Section 14 of the 1899 Rivers and Harbors Act (33 U.S.C. 408), often referred to as Section 408, requires any Federal entity wishing to make a modification to a project originally authorized by Congress and built by USACE to receive a permit from USACE to assure that the modification does not injure the public interest or impair the existing project's usefulness. Therefore, for most harbor projects and for channel or inland waterway improvements USACE would need to issue a 408 permit as well as a 404 permit even if there were no Federal funds involved in the modification.

[101] The Administration's fiscal 2013 budget calls for a 12 percent increase from fiscal 2012, rising funding to $848 million, representing about half the annual revenues deposited to the fund. The Administration argues that this level of funding has proven adequate to maintain the existing harbor infrastructure. Nonetheless, there has been some congressional legislation proposed to increase the amount expended from the trust fund.

[102] A sufficient channel is not necessarily going to be one that is maintained to its authorized width and depth. Sufficiency of the channel depends upon traffic utilization patterns and currently is determined by analysis of such patterns during the budget justification process.

Port expansions to accommodate *post-Panamax* vessels present a different set of concerns. Harbor channel capacities at Gulf of Mexico and Eastern U.S. ports currently do not accommodate fully laden *post-Panamax* vessels. Many of these ports are currently being studied or implemented by USACE or non-Federal interest under Sections 203 or 204 of WRDA 1986.[103] The challenge going forward is to identify funding mechanisms to take advantage these opportunities against the backdrop of a fiscally constrained environment.

Inland Waterways Funding

Over the past five fiscal years the total appropriations for lock and dam improvements and for O&M of inland waterway navigation structures and channels have been relatively constant. Of the total appropriations, a large percent are from general revenues.

Decisions on funding for inland waterways improvements are made based on a USACE economic justification analysis and are accompanied by an environmental evaluation and mitigation plan. Funds for waterway improvements are drawn from the balance in the IWTF and are cost shared with general Federal revenues on a 50/50 basis.

There have been concerns expressed in Congress and by the barge industry about the adequacy of funding for lock improvements and about delays in planning and implementing projects.[104] At present there is industry support for raising the fuel tax to increase the revenues flowing to the IWTF and for accompanying that raise with other reforms that change the share of total costs for waterway improvements paid from general revenues. The current Administration, as well as the previous Administration, proposed replacing the fuel tax with a lock passage fee that also includes changes in the share of total costs borne by general revenues.

Decisions on appropriations for operations, maintenance and minor repair are made through a process that begins with requests made at the USACE district level and ends with allocations made in the President's budget. Modest adjustments in annual appropriations have been made in the past during the congressional appropriations process.

Within this budget context, the issue of concern is whether the level of collections for and disbursements from the IWTF, combined with Federal general appropriations, will be adequate

[103] The Water Resources Development Act of 1986 (Sections 203 and 204) includes provisions for non-Federal interests to undertake feasibility studies for harbor improvements. These studies are to be in accordance with guidelines promulgated by the Secretary of the Army. The Secretary would review the study results and make a recommendation to the Congress on whether the proposed improvement would warrant Federal financial support under existing cost-sharing policy. If the Congress authorized the proposed harbor improvement, the non-Federal interest could make expenditures for improvements, subject to obtaining necessary permits, and later seek reimbursement for the federal share of the total cost, including study costs. These provisions might expedite the planning and implementation of harbor improvement projects, but would not necessarily increase Federal appropriations made to such projects. In effect, the nonfederal interest and the nation would realize the benefits of the improvement; however, there is no assurance that reimbursement for the Federal cost share would be forthcoming. This same process could be followed for making improvements to inland waterways.

[104] See footnote 23.

to improve, operate and maintain channel and lock and dam facilities at levels sufficient to provide reliable service. The focus of this discussion about this issue has been on the revenues collected with the current fuel tax, the level of Federal general revenue cost sharing and consideration of possibly increasing costs of improvements and O&M. [105]

Options for Harbor Improvement and Harbor Maintenance Funding[106]

Option 1: Business as Usual for Harbor Improvement and Continued Maintenance

Harbor improvements would continue to receive Federal funding from general revenue appropriations and from the project cost share partner. Currently cost share partners raise revenues to meet their cost share obligations using multiple strategies including landside facility fees, appropriations from general state revenues and more. Under this "business as usual" approach, funding for the next decade would remain consistent with that provided during the past five years. Allocation of funds for harbor improvement would be made according to Administration budget priorities, based on analyses of project justification provided through the existing USACE evaluation and justification processes.

Funding for channel maintenance would draw upon revenues from the HMTF with the fee structure which generates revenues for the fund remaining unchanged. Allocations from the fund to harbor maintenance would be made by the Administration in consideration of the need to maintain channels without regard to the size of the HMTF revenue stream. Because of the continuing revenue streams dedicated to the HMTF, and because of the reserves in that fund, financial support for maintenance of existing channels would be assured, at least for the near term. [107]

Option 2: Increase Appropriations from General Federal Revenues for Harbor Improvements

With this option Congress would follow the traditional model of support for harbor improvements but would *increase* general revenues appropriated for funding harbor improvement projects. The decision to increase appropriations would be based on USACE analyses showing that investment would be economically justified and environmentally acceptable, i.e., that the investment is a high priority when compared with other Federal investments and the investment fits within overall Federal fiscal limits. Federal funds still would be matched with cost sharing by project sponsors following existing cost-sharing rules.

[105] Possible causes of increasing costs include fragility of aging structures at an increasing rate with time and increases in unit costs of construction and O&M.
[106] The options presented are illustrative only and do not represent any administration position.
[107] One argument made for not fully expending revenues received by the HMTF is that appropriations are adequate to meet the maintenance dredging requirements. However, maintaining a balance in the fund, with no clear plan for spending that balance on harbor maintenance, has drawn the attention of the World Trade Organization. The fundamental concern is that if the fund maintains a surplus over time then it is no longer a fee for government service but is rather a tax or duty on imports. Options 4 or 5 would be a way to avoid this criticism.

Allocation of funds for harbor improvement would be made according to Administration budget priorities, based on analyses of project justification provided through the existing USACE evaluation and justification processes.

With this option, maintenance dredging would continue to be funded from revenues collected at the current level of user fee, deposited to the HMTF and allocated to harbors on an annual basis following current practice. For the reasons described under Option 1, it is likely that revenues received by the HMTF would prove adequate to maintain channels at least over the next decade.

Option 3: Modify Authority to Use HMTF Revenues as Appropriations for Harbor Improvements

An alternative to seeking additional general Federal revenues would be to raise the fees collected for the HMTF and then extend the allowable use of those increased funds from maintenance to include investments in harbor improvement. [108]

The logic is that the beneficiaries of the improvement projects can be readily identified and such an increase would be an application of the "beneficiary pays" principle. Under this option, the decision-making process would remain—that is, the USACE planning process would determine which projects were economically justified and environmentally acceptable and would then receive appropriations for managing the construction of such projects. Channel maintenance would continue to be funded from the revenue enhanced HMTF.

Option 4: Increase Cost Share Contributions to Harbor Improvements

This option would increase total revenues by increasing the non-Federal contribution for every dollar of Federal appropriation. Under this option the HMTF balances would continue to be used for maintenance.

As an illustration, the cost-share requirement of 35 percent might be raised to 65 percent for depths up to 45 feet and Federal participation in harbor deepening might cease at 45 feet; at depths greater than 45 feet the total cost for any further deepening would be paid 100 percent by the non-Federal sponsor. Variations on these differences can be imagined, but the basic objective would be to increase the share of harbor improvements paid by a non-Federal entity.

Under this option, as the non-Federal cost share approached 100 percent, the question would be whether or not the investment being made would still need to pass a Federal benefit-cost justification test. In fact, the willingness of the sponsor (port or the state) to provide a substantial share of the cost would be evidence that the benefits of the project do exceed the costs to the non-Federal sponsor. In effect, this is an application of the "beneficiary pays" principle and is a "market like" test of the justification for the investment. However, some form

[108] While increasing such charges and depositing them to the HMTF would be an application of the "beneficiary pays" principle, such action might be subject to challenge unless the funds were disbursed expeditiously for the purposes of harbor improvement and maintenance.

of planning and evaluation would still be required by USACE to establish the Federal interest in making a Federal appropriation and in determining how the proposed activity would meet environmental protection requirements. Cost share partners would need to raise additional funds using existing or new revenue sources.

Opportunities for non-Federal sponsors to raise funds for harbor improvements (as well as maintenance) are discussed further under Option 5 below.

Option 5: Individual Port Initiative

Under this option the HMTF would be phased out, as would the current fees dedicated to the fund. Individual port authorities would include the costs of maintenance in their overall cost structure and would levy fees in whatever form they deem appropriate for cost recovery for harbor improvements and maintenance at their own facilities.

Infrastructure Bank Financing

If an infrastructure bank is created under Federal authority, provisions could be made to allow ports to borrow from that bank and then repay the bank with user fees collected. USACE analyses could continue and inform bank due diligence, and underwriting, supporting the bank's determination of the strength of the potential revenue stream from a given project, and potential risks associated with such projections.

Individual port authorities could secure the initial funding for harbor improvements by entering into partnerships with shippers who would use the improved and maintained harbor, and/or by other financing means. The funds borrowed or otherwise advanced for purposes of construction would be repaid using revenues from the same kinds of user fees now currently in place for paying cost share. [109]

The shift of responsibility for securing funds and repayment (relative to Options 1 through 4) would be accompanied by a parallel shift of responsibility for evaluating the justification for harbor improvements and maintenance. Each individual harbor authority would establish whether the expenditure of funds was economically justified as opposed to relying on USACE analyses. The shift of decision responsibility on whether to deepen the harbor, by how much and what depths to maintain from the USACE-led planning process to the individual port is the fundamental difference between this option and simply raising the required cost share for the harbors (Option 4).

However, this option will not remove USACE from playing a central role in harbor improvement and maintenance decision-making. First, to the extent that a harbor improvement modifies a project that was historically built under Federal authority, USACE would need to issue a 408

[109] With this option the required revenues will exceed those now required for paying current cost share.

permit that would affirm that the actions being proposed by a non-Federal entity are consistent with the original authorized purposes of the project. The requirements that would be applied in making this 408 determination would need to be specified.

Perhaps of greater significance is the fact that the USACE regulatory program would maintain its permitting authority over any harbor improvement project or maintenance request. Currently the environmental evaluation that determines what environmental requirements must be met is a responsibility of the USACE planning process. Under this option, that responsibility would shift to a non-Federal entity[110] but the USACE regulatory program would retain the final decision authority as to whether or not the proposed harbor improvement or maintenance activity is environmentally acceptable.

Discussion: Harbor Improvement and Harbor Maintenance

Based on analyses elsewhere in this report, under Option 1 harbor improvement projects now underway or anticipated would be delayed due to a lack of funding. Determining the consequences of such delay would require further analysis. One possible response to Option 1 is that individual ports would choose to move forward without Federal support. In fact, there is no barrier to individual ports choosing to pursue option 5 on their own. For these individual ports, Option 5 becomes the operable financing and funding strategy.

Among the options that increase funding, option 2 is the most simple administratively and there is reason to believe that the non-Federal cost-sharing requirements triggered by an increase in Federal general revenue appropriations could be met. However, recent budget allocations and the extremely tight fiscal environment in the future makes reliance on this option for future funding.

Option 3 would require congressional action and it is not clear if it would be supported by the shipping industry. The fact that fees now collected for the HMTF are not fully appropriated back to harbor maintenance may create doubts about whether any newly increased revenues would be expeditiously appropriated to harbor improvements. Additionally, efforts to increase revenues would fall completely on imports (for legal reasons) and could draw the scrutiny of the World Trade Organization as being an unwarranted tariff on trade. Finally, if Option 3 resulted in increases in the level of fees for the HMTF, some shippers could divert to non-U.S. ports to unload cargo. The extent of this effect is unknown.

Options 4 and 5 would make changes to current policy to assure that all revenues collected from port users are used for harbor improvement and maintenance. Individual ports could choose their own user fees and taxes for covering costs. For example, a port could choose to levy charges on vessel draft instead of value of cargo, which would more directly relate to the cost of

[110] It may be possible for the USACE planning staff to offer this environmental assessment service on a cost reimbursable basis to the non-Federal entity.

providing the channel capacity. Option 4 would require legislative change that would demand (and so would need) Administration support and congressional action.

As cost share approaches 100 percent under Option 4, the financial difference between it and Option 5 (individual port initiative) narrows. In fact, modifications to the current Federal investment decision criteria might be modified as the Federal share of total costs decreases. The possible attractiveness of Option 4, relative to Option 5, is that USACE would continue to do the environmental analysis and have the responsibility to defend that analysis (and the compensatory mitigation it calls for) as being adequate and in the national interest.

Option 5 is the most direct application of beneficiary based funding. There are reasons to believe that the larger ports would be able to raise fees and taxes sufficient to recover costs of improvements and maintenance. Individual ports would collect their own fees, repay their own debt and make their own decisions. National port capacity would be determined through a system of decentralized decisions made at individual ports on where to dredge and by how much.[111] Individual ports would take into account their location in relation to trade patterns (volume and value of cargo) to assess the demand for additional depth, evaluate their costs of making channel improvements and providing maintenance, and make a final assessment of whether the demand for channel depth would be sufficient to support levels of user fees and taxes adequate to cover costs.

The resulting “market like” competition among the ports, constrained by the need to meet environmental requirements set by USACE permitting, could lead to more rapid decisions. The case for inter-port competition is that the result will be an efficient size and distribution of channel capacity. All harbors would not be at maximum depths for fully loaded ships. The network of ports, their channel capacity and origin-destination transport patterns would adjust such that some ports would accommodate heavily laden ships and other ports might become regional ports for light-loaded ships. Whether the result from this port competition model would yield the efficient allocation and capacity for the port network would need further evaluation.

This efficiency argument for Option 5 requires ports to base their user fees on the costs of dredging instead of a uniform tax rate on value of cargo. This would require shippers to bear the actual cost of improvements and maintenance and in so doing creates an incentive for shippers to favor the most cost-efficient ports. Of course, if ports begin to lose business as a result of this fee structure they would likely shift their revenue strategy to one that does not create an incentive for shipping to an alternative port. [112]

[111] State legislatures could have a role if sates choose to provide assistance.

[112] If individual harbors were to be responsible for their own deepening there is a risk that expenditures made for that deepening may not be recovered by user fees if those fees cause a change in shipment patterns. One way to address this for any given harbor would be to enter into a partnership agreement with the shipping company so that both parties are invested in the deepening activity and paying for the costs (perhaps repaying a loan) over a fixed period of time. Such a contract would be established between the harbor and one or more shipping companies.

Also, the efficiency case for inter-port competition will not apply for all harbors. At some harbors beneficiaries (users) by themselves may not be able to pay the full cost of improvements and operations over time, as required by Option 5. If Option 5 were followed in this situation, there may be a role for Federal general revenue subsidies on a case-by-case basis to supplement the tax and fee collections at those ports. Criteria and prioritization for establishing such subsidies would need to be developed, and should consider the characteristics of each project, including the economic merits.

A different perspective would challenge the efficiency case for Option 5. From this perspective, USACE-led planning is needed to define and then create an optimal allocation of harbor capacity across ports. [113] For Options 1 through 4, USACE could apply investment optimization models to recommend allocation of improvement funds to individual harbors in accord with minimizing the total costs of origin to destination transport of goods (or some other objective function). This model would replace individual harbor by harbor justification as is currently done now. The reality is that efforts at such multiport analysis have been attempted over many decades and proven to be both technically challenging and politically difficult to implement as a budget guide. [114]

Finally, in all options USACE would be responsible for the final determination of whether the proposed action is environmentally acceptable. Under Options 1 through 4, USACE would retain the responsibility for completing analyses needed for establishing the environmentally acceptable project, considering mitigation issues, and then would issue permits for the project instruction. In fact, the ability to navigate the regulatory process in ways that will expedite decision-making on harbor development is one of the principal reasons given for maintaining a significant USACE role in the planning and execution of harbor deepening projects. Under Option 5, the USACE role would be one of review of a ports application for a permit.

There remains a concern that environmental regulatory processes and permitting will continue to be a source of delay in all options (1-5). This concern may be addressed in part by the Administration's issuance of Executive Order 13604, "Improving Performance of Federal Permitting and Review of Infrastructure Projects" (March 22, 2012).

The expressed intent of the Executive Order is "…to significantly reduce the aggregate time required to make decisions in the permitting and review of infrastructure projects by the Federal Government, while improving environmental and community outcomes…" The Executive Order applies to reviews of "…improvements in Federal permitting and review

[113] There are efficiency arguments that can be made for centralized planning and investment and for inter-port competition. The arguments are complicated and would need to be considered in greater detail if Options 1-4 are being considered as an alternative to Options 5.

[114] A practical concern is that harbors investing on their own may not make justified investments (revenues prove inadequate to recover the cost of that advanced investment) and will seek assistance from Federal taxpayers even if the original investment was not nationally justified. For this reason, Option 4 would be a preferred response to the need for more funding relative to Option 5.

processes for infrastructure projects in sectors including surface transportation, aviation, *ports and waterways [*emphasis not in original], water resource projects, renewable energy generation, electricity transmission, broadband, pipelines…" The Executive Order sets in place a process to develop procedures to implement this expressed policy.

Options for Inland Waterways Improvements, Operations, Maintenance and Repair

Option 1: Business as Usual for Improvements and O&M

Appropriations for inland waterway improvements would continue to be from a combination of general Federal revenues and disbursements from the IWTF, and would be constrained by the revenues realized from the existing fuel tax revenue stream. Allocation of funds from these two sources would continue to be made according to Administration budget priorities in consultation with the Inland Waterways Users Board. Under this option total funding for the next decade would remain consistent with that provided during the past five years. Investments that drew upon either revenue source would continue to be based on analyses of project justification provided through the existing USACE evaluation and justification processes.

Financial support for maintenance and navigation lock and dam operations and repair would continue to be funded from general revenues at the same level as the average of the past five years.

Option 2: Increase Fuel Tax and Appropriations for Waterway Improvements and O&M

With this option the Administration and Congress would follow the traditional model of support for inland waterway improvements but authorize an increase in the fuel tax that increases the available balance in the IWTF.

At the same time, the Administration and Congress would provide increases in Federal appropriations to track with the increased revenues flowing into the IWTF. Depending upon the revenues from the fuel tax, they could reduce the share of total costs that is paid from general appropriations. The Administration and Congress would need to agree to an increase or decrease in the cost-share distribution. However, a requirement of this option would be that the total amount appropriated each year increases, even if the distribution between general revenues and withdrawals from IWTF change.

USACE analyses would continue to be the basis upon which expenditures for inland waterway improvements would be deemed economically justified and environmentally acceptable. [115]

[115] See the discussion of E.O. 13604 above.

A variation on this option would allow increases in the fuel tax revenues to be used in waterway O&M. The use of IWTF funds for O&M would represent a major change in the source of funds for maintenance. However if the additional revenues realized from increases in the fuel tax were dedicated to O&M, such increases could not replace current Federal appropriations if the total budget for O&M were to increase.

Option 3: Replace the Fuel Tax with a Vessel Use Fee and Increase Appropriations for Waterway Improvements and O&M

With this option the fuel tax would be eliminated and replaced with vessel user fees (lock passage fees or segment tolls)[116]. The user fees could be related to the costs of improving a lock, O&M at a lock, the size of the lock, the value of the cargo passing through the lock, the congestion at the lock (higher fees when the lock is congested) or any combination of the above. Special fees for recreational boats passing through the lock could be included.[117] The segment toll, however levied, would be related to the costs of maintaining and operating locks and channels of the waterway segment. (See further discussion of segment tolls under option 5, below). Revenues from the vessel user fees would continue to be deposited to the IWTF. Under this option the distribution of costs for waterway improvement and O&M that is paid from general revenues and the IWTF could be the same as under Option 1 (the current distribution) or could be modified to either increase or decrease the non-Federal share. However, a requirement of this option would be that the total amount appropriated each year increases, even if the distribution between general revenues and withdrawals from IWTF change.[118]

USACE analyses would continue to be the basis upon which expenditures for inland waterway improvements and O&M would be deemed economically justified and environmentally acceptable. [119]

Option 4: Maintain the Current Fuel Tax and add a Vessel User Fee to Increase Appropriations for Waterway Improvements and OMR&R[120]

With this option the fuel tax would be unchanged and a vessel user fees (as described above) would be assessed on an annual basis.

Revenues from the user fees would continue to be deposited to the IWTF. Under this option the distribution of costs for waterway improvement that is paid from general revenues and the IWTF would continue to be 50/50. However, a requirement of this option would be that the total amount appropriated each year increases.

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[116] A version of this option was included in the Administration's FY13 budget.
[117] Option 3 would redistribute the user fee burden to those who use the lock system in comparison to the fuel tax that is borne by all waterway users.
[118] This option could allow for the use of IWTF funds for O&M.
[119] See the discussion of E.O.13604 above.
[120] The Administration transmitted a legislative proposal to the Congress to reform the laws governing the Inland Waterways Trust Fund as part of the Jobs Bill proposal in September 2011.

USACE analyses would continue to be the basis upon which expenditures for inland waterway improvements and OMR would be deemed economically justified and environmentally acceptable.

Option 5: Public-Private Partnerships

The creation of Public-Private Partnerships (PPPs) has been proposed as a solution to supporting infrastructure modernization in a number of different venues. The success in forming such partnerships varies, but there are successes that can be pointed to for what has been termed "fixed guideway" infrastructure. However, a basic requirement for private participation in a PPP is assurance that there will be adequate revenues to allow the private entity to recover its costs and earn a return on investment from joining the partnership. Therefore, for a PPP to work in the inland waterway context it would require a commitment on behalf of the federal government to honor payment commitments made in the PPP contracts.

A PPP contract would define the sharing of risk from sources outside the control of either party (e.g., unexpected technical difficulties in executing the project) and the retention of other risks by the public entity (e.g., changes in regulatory rules or regulatory decisions that affect costs or technical feasibility[121]). Therefore, for a PPP to work in the inland waterway context would require contracts that address the sharing and assignment of these risks.

Option 3 addresses the problem of inadequate access to financial resources for making *immediate* improvements and for critical O&M on an aging infrastructure. USACE would divide inland waterways into segments (for current planning USACE recognizes 27 independent segments), recognizing the interconnectedness of certain those segments. The priorities for work on the segments would be defined principally by an assessment of the need for new investment and by the historic operation and maintenance costs per ton-mile traffic movement. One preliminary illustration of how this might be done is offered by the "*Inland Waterways Capital Development Plan*" that was prepared and submitted to Congress at the direction of the Inland Waterways Users Board in 2010. [122]

For priority segments, USACE would then issue requests for proposals for improvements and/or maintenance and repair over a fixed-term contract (say 30 years). In those requests for proposals USACE would specify what services were expected to be provided by the private partner, when the services would be realized, and would request a repayment schedule for the provision of those services.[123]

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[121] See the discussion of E.O. 13604 above.

[122] The Inland Waterways User Board might be reconfigured in terms of its authority, membership and purpose to act in concert with USACE in participating in the PPP process.

[123] The PPP agreement would need to avoid and minimize effects on current non-commercial shipping waterway users. For example, recreational uses may need to be protected or accommodated or the reliability of water supply intakes. Even if these are not currently authorized purposes, accommodating such users may be necessary if the PPP is to be politically acceptable.

The private partner could be asked to design and/or build and/or operate and maintain channels and navigation locks and dams in return for an annual payment. USACE would provide support to[124] and oversight over the private partner, assuring that the terms of the contract with respect to lock operations and channel maintenance were honored. The private entity would secure all the necessary financing for waterway improvement or O&M.[125] The Federal government would agree to compensate a private partner for expenses incurred in segment improvements and maintenance. Revenues needed to honor the contracts could be derived from any or a combination of the following: general appropriations, raising the fuel tax, lock passage fees, lock congestion fees, or segment passage fees. [126] A segment passage fee would be relatively simple to administer with current technology. GPS tracking is now standard practice for all tows. It would be possible to determine when a tow has utilized the capacity of a particular segment. The charge for use of that segment would be in relation to the cost of operating, maintaining and repairing infrastructure for that segment and could be based upon a fixed ton-mile charge, perhaps adjusted for the value of the cargo.

The PPP contract would specify which of these revenue sources would be used by the Federal government to make payments to the private entity.

Discussion: Waterway Improvement and O&M

Options 2, 3, and 5 are similar in the sense that all seek to raise the level of initial funding for waterway improvements and O&M above "business as usual." The main difference is that under Option 5 the initial funding is secured through private partnership agreements allowing investments to move forward more quickly than they would under the current planning and budgeting process. The likelihood of such revenues coming from general Federal appropriations is low given current budget realities. Therefore, for Option 5 to be viable there is a need to increase revenues paid by the users. Especially important is that the added revenues are dedicated to honoring the contracts entered into with the private provider of improvement and maintenance services. It is this contractual commitment that makes this option attractive as a method for increasing funding. Specifically, the contractual commitment creates an expectation that all revenues collected and deposited to the IWTF will be used for the purposes of honoring

[124] A simple example is that USACE would continue to collect and report traffic volume, cargo type, as well as origins and destination of shipments.

[125] A public-private partnership contract that relies on beneficiary based revenues is unlikely to work for what have been termed "low use" waterway segments, unless there were a commitment of general revenue and a share of the dedicated fuel tax to the PPP contract. The case that would need to be made for continued improvement and maintenance of those segments that parallels the case that might be made for low-use harbors, as described above.

[126] Tax and fee collection is an example of another function that could be retained by USACE. The barge companies who are the immediate users of the waterways would seek to pass on the costs of any fees or taxes to their customers, the shippers of goods (grains, coal, fertilizer, etc.). The shippers in turn would seek to pass on costs to the buyers of their products. The final distribution of the burden of the fees and taxes would depend on the demand for the product (technically, in economics, the elasticity of demand) and the availability of alternative transportation modes.

the contracts and will be supplemented as needed by appropriations from the general budget appropriation process. [127]

[127] No current Congress can obligate a future Congress to a particular spending plan. However, there is experience that provides evidence that the Federal government would honor long-term contracts and that evidence may increase the confidence of the private entity that the agreed-to revenues would be forthcoming.

Chapter 6: Additional Considerations

National Intermodal Freight Transportation Strategy

A modernization strategy should be part of an overall national intermodal freight transportation strategy. While the three dominant freight carrier modes – water, rail and truck – compete for market share, there is a growing recognition of the need for multi-modal linkages and for infrastructure investments to be coordinated across the modes to ensure that they complement each other and ensure the best overall use of the available funds for the Nation. This can be supported by prioritizing navigation investment according to their multi-modal connectivity. On March 1, 2012 USACE signed a Memorandum of Understanding with the Department of Transportation on collaboration with a purpose to identify and capitalize on opportunities to improve the Nation's transportation infrastructure investments where shared equities exist.[128]

A national intermodal freight transportation strategy could also consider local sponsor commitment in terms of cost sharing and community support should be taken into consideration. Opportunities to contribute the Administration's initiative to increase exports, energy independence and enhance national security must be considered.

Adaptive Management

This report also recognizes the uncertainty held in future modernization actions – which depend on specific location, types of actions taken and other unknowns – indicate that an adaptive approach to modernization is a wise strategy. When infrastructure projects are planned, designed and implemented, they should explicitly include the concept of adaptive management (i.e., the identification of sequential decisions and implementation based on new knowledge and thresholds). It is an important concept that should be included in both the system modernization strategy and individual projects identified for implementation under that strategy. Adaptive management has been primarily used in improving environmental management policies and practices. However, it can also be applied to developing sustainable solutions in navigation.

Employing adaptive management techniques in the development of a modernization strategy and decisions on specific infrastructure investments makes sense given the complex nature of trade routing and inherent uncertainties and risks associated with forecasts, not only of economic future conditions, but physical future conditions such as climate change, sea level change and social future conditions such as population demographics and distributions.

[128] See appendix C for a copy of this MOU.

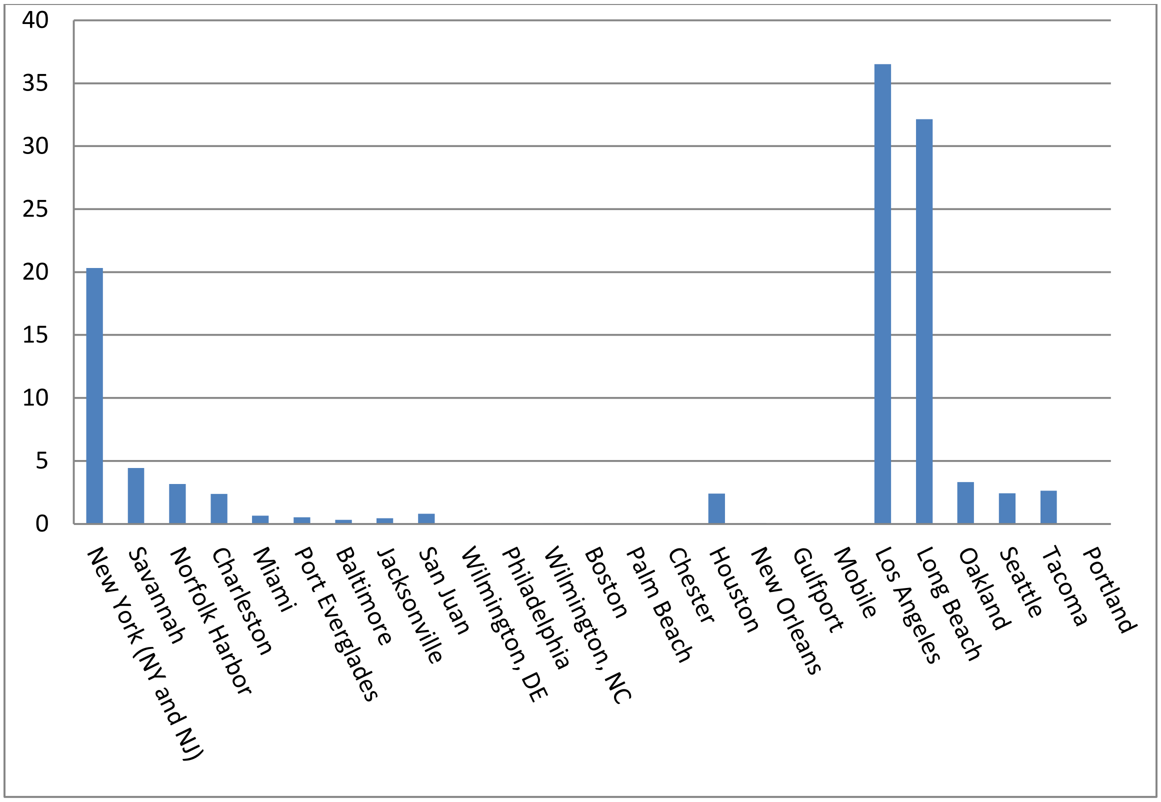
Within the context of navigation channels, adaptive management techniques could be adopted to allow channel and turning basin dimensions to be adjusted during normal maintenance dredging to adjust to actualized market conditions. This would resemble the approach of phased construction through the implementation of separable elements, but would allow conditional authorization of future elements that are currently economically unjustified. The NEPA documentation for the project would be required to cover the impacts of all the envisioned future elements. An example that illustrates this approach is the recently completed study for the Port of Savannah. The port sought a project depth of 48 feet. USACE economic evaluation techniques led the Division office to recommend a depth of 47 feet. Considerable time and energy was spent on this issue. If there is justification to deepen to 48 feet in the future, the Port of Savannah will have to start the entire process over from the beginning. An adaptive management approach have allowed the project to move forward with the 47 feet depth; if time shows justification for a 48-foot channel the deepening could be done as part of the regular maintenance cycle without the need to go through the entire planning process again. An adaptive management approach could reduce study time, reduce conflict and improve USACE responsiveness and product delivery.

Coastal Port Service Area

One factor the Congress has asked IWR to consider in this report is the current and projected population trends that distinguish regional ports and ports that are immediately adjacent to population centers.

To examine this issue IWR developed a port index of regional trade. This index can be used to gain insight into the degree a port serves a local catchment area or a larger regional community.[129] The index was developed for container ports. It considers the population adjacent to the port and the total number of TEUs moving through the port for the years 2005-2009. The results are presented in Figure 38 below. The index reveals three distinct categories of ports. The ports with the largest indices could be called "national ports." They are Los Angeles, Long Beach and New York. The second category is "regional ports." Regional ports include: Savannah, Oakland, Norfolk Harbor, Tacoma, Charleston, Houston and Seattle. Local ports include Miami, Port Everglades, Baltimore, Jacksonville, San Juan, Wilmington DE, Philadelphia Wilmington NC, Palm Beach, Chester, New Orleans, Gulfport, Mobile and Portland. The index shown in Figure 40 was developed based on freight traffic measured in TEUs.

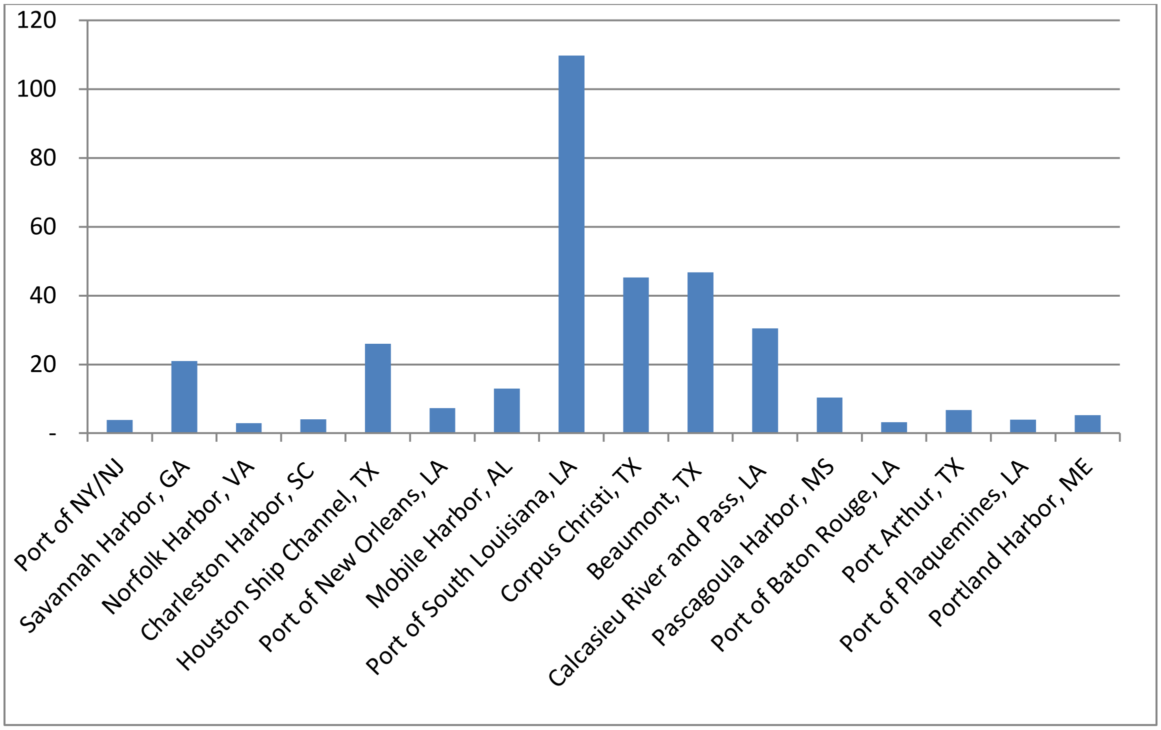
[129] USACE Institute for Water Resources



Source: USACE Institute for Water Resources

Figure 38: IWR Port Index of Regional Trade – Traffic Measured in TEUs

A similar analysis was conducted measuring freight traffic in tons for consideration of bulk ports. The results for selected ports are presented in Figure 39. This index shows the Port of South Louisiana to be a "national" port. Regional ports are Savannah, Houston Ship Channel, Corpus Christi, Beaumont and Calcasieu River and Pass.



Source: USACE Institute for Water Resources

Figure 39: IWR Index of Regional Trade – Traffic Measured in Tons

As a general observation it may be surmised that investments in "national" or "regional" ports will have a wider distribution of benefits than those that serve a local catchment area. Preference may be given to investments in ports that serve a broader community as part of a national transportation strategy.

Report Observations and Findings

The main observations and findings of the report are as follows:

- World trade and U.S. trade is expected to continue to grow.
- Post-Panamax size vessels currently call at U.S. ports and will dominate the world fleet in the future.
- These vessels will call in increasing numbers at U.S. ports that can accommodate them.
- Along the Southeast and Gulf coast there may be opportunities for economically justified port expansion projects to accommodate post-Panamax vessels.
  - This is indicated by an evaluation of population growth trends, trade forecasts and an examination of the current port capacities. As well as completed and ongoing Corps feasibility studies.
  - Investment opportunities at specific ports will need to be individually studied.

- The potential transportation cost saving of using post-Panamax size vessels to ship agricultural products to Asia, through the Panama Canal may lead to an increase in grain traffic on the Mississippi River for export at Gulf ports.
  - An analysis indicated the current Mississippi River capacity is adequate to meet potential demand if the waterways serving the agricultural export market are maintained.
  - A need for lock capacity expansion is not indicated.
- Despite the uncertainty in market responses to the deployment of post-Panamax vessels and the expansion of the Panama Canal, individual investment opportunities for port expansion can be identified using established decision making under uncertainty techniques. Adaptive management techniques can also be used to address uncertainty issues. Preliminary estimates indicate the total investment opportunities may be in the $3-$5 billion range.
- Environmental mitigation costs associated with port expansion can be significant and will play an important role in investment decisions.
- The primary challenge with the current process to deliver navigation improvements is to ensure adequate and timely funding to take advantage of potential opportunities.
  - A notional list of financing options is presented to initiate discussion of possible paths to meet this challenge—it is anticipated that a variety of options may be desirable, and in all cases individual project characteristics, including its economic merits, would need to be considered in selecting the optimal financing mechanisms.

A Final Thought

There is uncertainty in the navigation industry regarding the expected impacts from the deployment of *post-Panamax* vessels. Current fiscal conditions and budget priorities suggest the Federal government's role may become more limited than in the past. Within the navigation program there is competition between maintenance of our current projects and capacity expansion.

Maintaining the capacity of our major ports and waterways and expanding port capacity when, where, and in a way that best serves this Nation will require leadership at all levels of government, and partnership with ports and the private sector. The main challenges are to continue to maintain the key features of our current infrastructure, to identify when and where to expand coastal port capacity, and to determine how to finance its development. Congress, by directing the preparation of this report, and the Administration, by proposing a White House task force on navigation, have demonstrated a coincident interest in this topic, indicating an opportunity to jointly develop appropriate guidelines, methods, and legislation to establish a national investment strategy.

Appendices

Appendix A

Organizations providing written comments:

Port of Seattle

Port of Tacoma

Port of Virginia

Port of Houston

Port Miami

Port of Baltimore (Maryland Port Administration)

Port Authority of NY and NJ

American Association of Port Authorities

South Carolina State Port Authority

Florida Port of Council

Texas Transportation Institute

Pacific Northwest Waterways Association

GICA (Gulf Intracoastal Association)

Lake Carriers Association

Dredging Contractors of America

National Waterways Conference

Fifth Coast Guard District

EPA

USACE NAN

USACE, NAO

Broward County

Big River Coalition

NRDC (Natural Resources Defense Council)

National Wildlife Federation/ Sierra Club

Center for a Sustainable Coast

Taxpayers for Common Sense

Environmental Defense Fund

Izaak Walton League of America

Chip Meador

Paul Pollinger

Appendix B

Term	Definition
Beneficiary Based Funding	Payments for the cost of construction, operation, maintenance and repair of harbors, channels, locks and dams using revenues from user fees or a dedicated tax source. A user fee is a direct charge paid voluntarily by the user of the harbor or waterway; failure to pay the charge results in exclusion from use (e.g., a lock passage fee or a wharf access fee). In contrast, a dedicated tax is a required payment to a government entity, enforced by threats of sanction for nonpayment rather than by denial of a use (e.g., a tax on fuel). Revenues from user fees and dedicated taxes are often deposited to a government managed trust fund. This "beneficiary pays" funding strategy has been advocated for assuring the efficient use of funds for investment and maintenance. However efficiency requires more than just collecting revenues from beneficiaries; efficiency requires that expenditure of those funds be the responsibility of those entities who pay for the service. Otherwise, fees and dedicated systems cannot be distinguished from general revenues.
Berths	Berth is the term used in ports and harbors for a designated location where a vessel may be moored, usually for the purposes of loading and unloading. Berths are designated by the management of a facility (e.g., port authority, harbor master). Vessels are assigned to berths by these authorities. Most berths will be alongside a quay or a jetty (large ports) or a floating dock (small harbours and marinas). Berths are either general or specific to the types of vessel that use them in the process. The size of the berths varies from 5-10m for a small boat in a marina to over 400m for the largest tankers.
Bulk cargo	Bulk cargo is commodity cargo that is transported unpackaged in large quantities. This cargo is usually dropped or poured, with a spout or shovel bucket, as a liquid or as a mass of relatively small solids (e.g. grain, coal), into a bulk carrier ship's hold, railroad car, or tanker truck/trailer/semi-trailer body. Smaller quantities (still considered "bulk") can be boxed (or drummed) and palletised. Bulk cargo is classified as liquid or dry.
Cascade	Cascading refers to the shifting of vessels from one trade service to another that occurs when new, large vessels are deployed on the longest and largest trade service – Asia to Northern Europe. The displaced "smaller" vessels on that service are forced to re-deploy to the next most efficient service for that vessel size, in turn displacing another set of vessels, and so on.
Container	A shipping container is a container with strength suitable to withstand shipment, storage and handling. Shipping containers range from large reusable steel boxes used for intermodal shipments to the ubiquitous corrugated boxes. In the context of international shipping trade, "container" or "shipping container" is virtually synonymous with "(standard) intermodal freight container" (a container designed to be moved from one mode of transport to another without unloading and reloading).

Cost Recovery	A requirement that all costs for construction, operation, maintenance and repair costs incurred over a period of time be matched by general tax revenues and receipts from user fees in dedicated taxes. Since benefits are realized over time, payments toward cost recovery may be received over several years. Upfront costs will typically require sale of bonds; repayment of bond debt would be spread over some period of project life.
Cost sharing	A legally mandated sharing of the costs for construction, operations, maintenance, repair, rehabilitation or replacement for harbor and waterway improvements between the Federal government and a non-Federal entity. Cost-sharing is a requirement for Federal budgetary participation in harbor and inland waterway improvements.
Cube trade	See "Volume Trade"
Docks	See "Wharf"
Financing	The advancement of funds from a public, quasi-public or private entity to an entity initially responsible for the costs of improvements and O&M at harbor and waterway facilities. The responsible entity then uses a combination of general revenues, user fees and dedicated taxes to repay the incurred debt.
General Revenue Funding	Appropriations for the cost of construction, operations, maintenance and repair of harbors and waterways made from general revenues of Federal and non-Federal governments.
Hinterland	The area from which products are delivered to a port for shipping elsewhere is that port's hinterland.
Infrastructure	Infrastructure is basic physical and organizational structures needed for the operation of a society or enterprise, or the services and facilities necessary for an economy to function. It can be generally defined as the set of interconnected structural elements that provide framework supporting an entire structure of development. It is an important term for judging a country or region's development. The term typically refers to the technical structures that support a society, such as roads, water supply, sewers, electrical grids, telecommunications, and so forth, and can be defined as "the physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions." Viewed functionally, infrastructure facilitates the production of goods and services and also the distribution of finished products to markets, as well as basic social services such as schools and hospitals; for example, roads enable the transport of raw materials to a factory. In military parlance, the term refers to the buildings and permanent installations necessary for the support, redeployment and operation of military forces.
Infrastructure Bank	A chartered government institution that makes or guarantees loans for non-Federal infrastructure improvements in anticipation of repayment through future dedicated revenue streams, such as revenues from user fees or dedicated taxes.

Inland waterway	The U.S. Army Corps of Engineers (USACE) is responsible for 12,000 miles (19,000 km) of the waterways. This figure includes the intracoastal waterways such as the Gulf Intracoastal Waterway and the Atlantic Intracoastal Waterway. Most of the commercially important inland waterways are maintained by USACE, including 11,000 miles (18,000 km) of fuel taxed waterways. Commercial operators on these designated waterways pay a fuel tax, deposited in the Inland Waterways Trust Fund, which funds half the cost of new construction and major rehabilitation of inland waterways infrastructure.
Intermodal	Intermodal freight transport involves the transportation of freight in an intermodal container or vehicle, using multiple modes of transportation (rail, ship and truck), without any handling of the freight itself when changing modes.
Jetty	A jetty is any of a variety of structures used in river, dock and maritime works that are generally carried out in pairs from river banks or in continuation of river channels at their outlets into deep water; or out into docks and outside their entrances; or for forming basins along the sea-coast for ports in tideless seas. The forms and construction of these jetties are as varied as their uses (directing currents or accommodating vessels), for they are formed sometimes of high open timber-work, sometimes of low solid projections, and occasionally only differ from breakwaters in their object.
Long ton	Long ton is the name for the unit called the "ton" in the U.K. system of measurement. One long ton is equal to 2,240 pounds (1,016 kg), 1.12 times as much as a short ton. It has some limited use in the U.S. and is often used to measure the displacement of ships. (see “Short Tons” for a more in-depth discussion of the term “ton.”
Multi-modal	See "Intermodal"
Panamax	*Panamax* refers to vessels sized to the maximum allowed by the dimensions of the pre-expansion Panama Canal.
Post-Panamax	*Post-Panamax* refers to vessels that are too large to fit through the channels and locks of the pre-expansion Panama Canal. Several classes of vessels would be appropriately called *post-Panamax*. With the expansion of the Canal expected to be complete in 2014, several classes of *post-Panamax* vessels will be able to transit the Canal. Those vessels sized to the maximum allowed by the new dimensions of the expanded canal have been dubbed "New Panamax" and larger vessels have been dubbed "Neo Post-Panamax" or “Super Post-Panamax.”
Short ton	The short ton is a unit of measurement equal to 2,000 pounds (907.18 kg). In the U.S. most references to “ton” refer to the short ton. There are other measurements of a ton including the metric ton (tonne) equal to 1,000 kilograms (2,204.62 lbs) or the long ton equal to 2,240 pounds (1,016.05 kg). There are some U.S. applications for which “ton” means long tons (e.g., Navy ships) or metric tons (e.g., world grain production figures). Both the long and short ton are defined as 20 hundredweights. In the U.S. system a hundredweight is 100 pounds but would be 112 pounds in the U.K. system (or approximately 100 kg).

TEU	The twenty-foot equivalent unit (often TEU or teu) is an inexact unit of cargo capacity often used to describe the capacity of container ships and container terminals. It is based on the volume of a 20-foot-long (6.1 m) intermodal container, a standard-sized metal box which can be easily transferred between different modes of transportation, such as ships, trains and trucks. One TEU represents the cargo capacity of a standard intermodal container, 20 feet (6.1 m) long and 8 feet (2.44 m) wide. There is a lack of standardization in regards to height, ranging between 4 feet 3 inches (1.30 m) and 9 feet 6 inches (2.90 m), with the most common height being 8 feet 6 inches (2.59 m). Also, it is common to designate 45-foot (13.7 m) containers as 2 TEU, rather than 2.25 TEU.
Transshipment	The transshipment of containers at a container port or terminal can be defined as the number (or proportion) of containers, possibly expressed in TEU, of the total container flow that is handled at the port or terminal and, after temporary storage in the stack, transferred to another ship to reach their destinations. The exact definition of transshipment may differ between ports, mostly depending on the inclusion of inland water transport (barges operating on canals and rivers to the hinterland). The definition of transshipment may: include only seaborne transfers (i.e., a change to another international deep-sea container ship) or include both seaborne and inland waterway ship transfers (sometimes indicated as water-to-water transshipment). Most coastal container ports in China have a large proportion of riverside “transshipment” to the hinterland. In both cases, a single, unique, transshipped container is counted twice in the port performance, since it is handled twice by the waterside cranes (separate unloading from arriving ship A, waiting in the stack, and loading onto departing ship B).
Trust fund	A government established and managed account that accumulates the revenues from user fees and dedicated taxes. The managers of the fund make decisions about the disbursements from the fund.
Volume trade	Services that tend to fill vessels to their volume capacity are considered "volume trade." They generally require channel depths providing clearance less than the vessel’s maximum draft.
Weight trade	Services that tend to fill vessels to their weight capacity are considered "weight trade." They require channel depths providing clearance of the vessel’s maximum draft.
Wharf	A wharf or quay is a structure on the shore of a harbor where ships may dock to load and unload cargo or passengers. Such a structure includes one or more berths (mooring locations), and may also include piers, warehouses, or other facilities necessary for handling the ships.

Appendix C

Memorandum of Understanding between U.S. Department of the Army and U.S. Department of Transportation

MEMORANDUM OF UNDERSTANDING
BETWEEN
U.S. DEPARTMENT OF THE ARMY
AND
U.S. DEPARTMENT OF TRANSPORTATION

I. PARTIES

This Memorandum of Understanding (MOU) confirms a collaborative relationship between the U.S. Department of Transportation (DOT) and the U.S. Department of the Army (Army), collectively referred to herein as "the Parties."

II. AUTHORITIES

Department of the Army:

1. 33 U.S.C. § 2281, which directs the Secretary of the Army to consider enhancements to U.S. economic development in planning water resources development projects.

2. 33 U.S.C. § 2323a, which permits the Secretary of the Army to engage in activities in support of other Federal agencies to address problems of national significance to the United States related to water resources, infrastructure development, and environmental protection.

Department of Transportation:

1. 49 U.S.C. § 301(3)&(4), which direct the Secretary of Transportation to:

a. Coordinate Federal policy on intermodal transportation and initiate policies to promote efficient intermodal transportation in the United States; and
b. Promote and undertake the development, collection, and dissemination of technological, statistical, economic, and other information relevant to domestic and international transportation.

III. PURPOSE

The purpose of the collaboration is to identify and capitalize on opportunities to improve the Nation's transportation infrastructure investments where shared equities exist.

IV. OBJECTIVE

The objective of the collaboration is to synchronize the Parties' strategies and coordinate and align infrastructure project proposal criteria and project evaluation and selection methodologies in support of a multimodal transportation network that improves the nation's economic competitiveness.

The information shared is not expected to include information about individuals (personally identifiable information PII "privacy protected" information), but could include business proprietary information (confidential business information—CBI) received from business entities.

Any information sharing must comply with applicable disclosure restrictions and practices (e.g., sharing of CBI may require the consent of, or notice to, the submitters of the information).

When the systems and information are known, each Party will prescribe appropriate restrictions on further dissemination and use, and appropriate labeling and handling instructions, for any information that is sensitive, to ensure the information remains confidential and to ensure each Party and/or the submitters retain control over the information.

VI. PERIOD OF AGREEMENT

The effectiveness of this MOU will commence upon full execution of the final signatures of the Parties, and will remain in effect indefinitely from the date of execution, unless the MOU is terminated by mutual agreement or by either side with thirty days notice.

VII. MODIFICATION

This MOU or subsequent annexes may be amended or modified at any time by mutual agreement of the Parties. Such modifications shall be in writing and will take effect upon execution by the Parties.

VIII. OTHER PROVISIONS.

Generally: All provisions of this MOU are subject to the availability of funds.

Severability: Nothing in this MOU or any related annex is intended to conflict with current statutes, regulations, orders, or directives of DOT, Army, or any other Federal agency or entity. If a provision of this MOU, or any annex, is determined to be inconsistent with such authority, then that provision will be invalid to the extent of such inconsistency, but the remainder of that provision and all other provisions, terms, and conditions of this MOU and any related annexes will remain in full force and effect.

Rights and Benefits: Nothing in this MOU is intended to diminish or otherwise affect the authority of any agency to carry out its statutory, regulatory or other official functions. This MOU is not a final agency action by any of the signatory agencies, and does not create any right or benefit, substantive or procedural, enforceable at law or equity by any party against the United States, its agencies or officers, State agencies or officers carrying out programs authorized under Federal law, or any other person. This MOU does not impose any legally binding requirements on Federal agencies, States, or the regulated public.

This MOU Does Not Involve Funding: This MOU is neither a fiscal nor funds obligation document. It does not obligate, commit or authorize the expenditure of funds and cannot be used as the basis for the transfer of funds. Any endeavor involving the reimbursement or contribution of funds between the Parties shall be in accordance with applicable laws, regulations, and procedures. Funding arrangements, if any, shall be the subject of separate agreements that will be subject to the availability of funds.

Disputes: Should disagreement arise in the interpretation of the provisions of this MOU, or related amendments and/or revisions, that cannot be resolved at the operating level, the area(s) of disagreement will be stated in writing by each Party and presented to the other Party for consideration. If agreement on interpretation is not reached within thirty (30) days, the Parties will forward the written presentation of the disagreement to respective higher level officials for appropriate resolution.

IX. CONTACT INFORMATION

For the purposes of exchanging information and coordinating activities under this MOU, the respective points of contacts for the Parties are as follows:

For Army: Chief of Operations, U.S. Army Corps of Engineers
For DOT: Chief Economist, Office of Transportation Policy

X. SIGNATURES

John Porcari, Deputy Secretary
U.S. Department of Transportation

Jo-Ellen Darcy, Assistant Secretary for the Army (Civil Works)
U.S. Department of the Army

U.S. Port and Inland Waterways Modernization:
Preparing for Post-Panamax Vessels

Institute for Water Resources

U.S. Army Corps of Engineers

June 20, 2012

US Army Corps of Engineers®

IWR
INSTITUTE FOR WATER RESOURCES

Planning Framework for the Levee Safety Risk Management

In Review at USACE/IWR

15pp.

(Not available for distribution.)

The Realities of Federal Disaster Aid: The Case of Floods

Carolyn Kousky and Leonard Shabman

(No Senior Author Assigned)

RfF Issue Brief 12-02, 2012

http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=21846

Also see: http://www.rff.org/Publications/WPC/Pages/How-Generous-Is-Post-flood-Disaster-Aid.aspx

WORKSHOP
On a New Unified National Program for Flood Risk Management
Conducted by Leonard A. Shabman

A New Approach to Defining the Federal Role in Flood Risk Management

University of Maryland
Bethesda, Maryland
November 18, 2012

USGS Award # G13AP00007 Modernizing U.S. Army Corps of Engineers Planning and Regulatory Policies and Programs Phase VI

Basic Information

Title:	USGS Award # G13AP00007 Modernizing U.S. Army Corps of Engineers Planning and Regulatory Policies and Programs Phase VI
Project Number:	2013VA162S
Start Date:	12/12/2012
End Date:	9/30/2014
Funding Source:	Supplemental
Congressional District:	
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Management and Planning, Economics
Descriptors:	
Principal Investigators:	Stephen H. Schoenholtz, Leonard Shabman

Publications

There are no publications.

No activity since inception

Information Transfer Program Introduction

The VWRRC supports timely dissemination of science-based information to policy- and decision-making bodies and to citizens. The VWRRC used its USGS 104(b) funds to support expert personnel with responsibilities related to the Center's outreach and collaborative programs. During the reporting period, the USGS 104(b) funds supported:

1. Preparation and electronic publication of the newsletter *Virginia Water Center.*
2. Partial administrative support for the Virginia Water Monitoring Council.
3. Partial support for production and management of the VWRRC webpage, VWRRC Facebook, VWRRC Twitter, and *Virginia Water Radio.*

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2011VA150B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	Ninth
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Stephen H. Schoenholtz, Kevin McGuire

Publications

1. Zimmer, M., S.W. Bailey, K.J. McGuire, and T.D. Bullen. 2012. Fine scale variations of surface water chemistry in an ephemeral to perennial drainage network. *Hydrological Processes.* DOI 10.1002/hyp.9449
2. Kruitbos, L.M., D. Tetzlaff, C. Soulsby, J. Buttle, S. Carey, H. Laudon, J. McDonnell, K. McGuire, J. Seibert, R. Cunjak, and J. Shanley. 2012. Implications of changing hydro-climatic controls for Plecoptera diversity in northern catchments. *Hydrobiologia.* DOI 10.1007/s10750-012-1085-1
3. Kelleher, C., T. Wagener, M. Gooseff, B. McGlynn, K. McGuire, and L. Marshall. 2012. Investigating controls on the thermal sensitivity of Pennsylvania streams. *Hydrological Processes.* 26(5): 771-785
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McGuire. 2013. Change in winter climate will affect dissolved organic carbon and water fluxes in mid- to high latitude catchments. *Hydrological Processes.* DOI 10.1002/hyp.9686

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18. Zipper, C.E., G. Holtzman, L.A. Shabman, K. Stephenson, J.L. Walker, and G. Yagow. 2012. A screening approach for nutrient criteria in Virginia: Report of the Academic Advisory Committee for the Virginia Department of Environmental Quality. Virginia Water Resources Research Center Special Report. SR51-2012, 85pp.
19. *Virginia Water Central,* April 2012 (No. 58), 40 pp.
20. *Virginia Water Central,* July 2012 (No. 59), 38 pp.
21. *Virginia Water Central*, November 2012 (No. 60), 44 pp.

Information Transfer and Outreach

Newsletter

Email distribution to 680 recipients and announcement/availability on VWRRC Web site.

Notifications to Virginia Water Monitoring Council List Serves

The VWRRC provides administrative support to the Virginia Water Monitoring Council (VWMC). The VWMC was formed to promote and facilitate coordination of water monitoring programs throughout the Commonwealth of Virginia. Membership in the VWMC is open to any person or organization with responsibility for or interest in water monitoring in Virginia. Weekly water-related announcements via list serve are provided to 550 members (representing more than 250 different organizations) of the VWMC. Announcements include information about conferences, workshops, total maximum daily load (TMDL) public meetings in Virginia, job openings, newly published reports, information posted on Web sites, and other pertinent information.

1. Distributed 41 sets of general announcements as e-mail messages to the VWMC membership; each message contained at least a dozen informational announcements, including: calls for papers, conference announcements, job openings, training opportunities, recently published reports, etc.
2. Developed 13 sets of special announcements and distributed these as email messages to the VWMC membership; these announcements pertained to VWMC-sponsored activities and information about beach-monitoring and water recreation as specified in grants from the Virginia Department of Health (VDH).
3. Weekly announcements are posted on the VWMC's website www.vwrrc.vt.edu/vwmc.

VWRRC Website

(www.vwrrc.vt.edu)

The VWRRC website is updated at least weekly and supports a Water News Grouper page, which is updated several times each week. The VWRRC website also serves as the portal for three other websites that the VWRRC manages:

1. Virginia Water Monitoring Council (http://www.vwrrc.vt.edu/vwmc/default.asp)
2. Virginia Department of Conservation and Recreation Stormwater BMP Clearinghouse (http://www.vwrrc.vt.edu/swc/)
3. Clinch-Powell Clean Rivers Initiative (http://www.vwrrc.vt.edu/cpcri/default.asp)

VWRRC is on **Twitter** at http://twitter.com/VaWaterCenter
and **Facebook** (http://www.facebook.com/pages/Blacksburg-VA/Virginia-Water-Resources-Research-Center/186479556264?v=wall)

Virginia Water Radio

(www.virginiawaterradio.org)

The VWRRC produces and hosts a weekly 5-minute radio show featuring summaries of recent water news, upcoming water events, and water-related sounds or music.

International Outreach Activities

1. Associate Director McGuire is invited member/co-leader of scientific steering group: Theme 2: Conceptualization of process heterogeneity, Predictions in Ungauged Basins (PUB) Initiative of the International Association of Hydrological Sciences (IAHS), 2008-present.
2. Director Schoenholtz was invited as a member of an international panel to evaluate the Swedish Future Forests Research Program Plan for 2013-2016, sponsored by MISTRA, The Swedish Foundation for Strategic Environmental Research.
3. VWRRC Faculty serve as referees for numerous international journals.

USGS Summer Intern Program

Basic Information

Start Date:	1/1/2012
End Date:	1/1/2012
Sponsor:	Simon, Nancy S
Mentors:	Nancy S Simon
Students:	Ahmad Abdul Ali

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Very Good
Technical interaction with USGS scientists	Good
Treatment by USGS as member of a team	Very Good
Exposure and access to scientific equipment	Very Good
Learning Experience	Very Good
Travel	About Right
Field Experience Provided	Too Little
Overall Rating	A

Additional Remarks

I enjoyed my time in USGS and liked very much working with great people.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	14	0	1	0	15
Masters	7	1	0	0	8
Ph.D.	7	0	0	0	7
Post-Doc.	0	0	0	0	0
Total	28	1	1	0	30

Notable Awards and Achievements