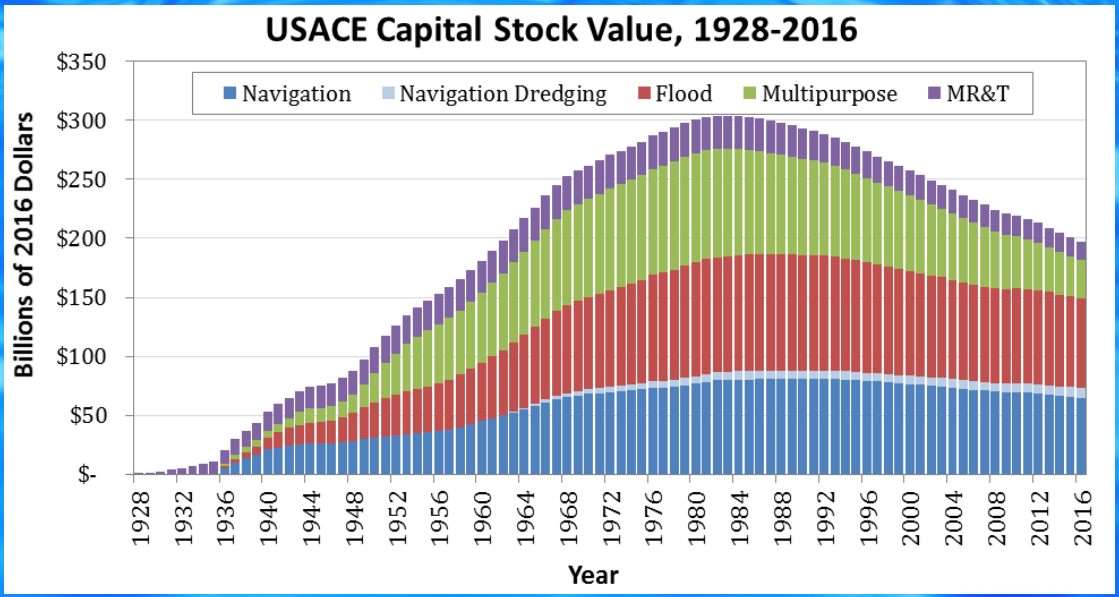
Institute for Water Resources

December 2018

Estimating USACE Capital Stock, 1928 to 2016

2018-R-03



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Institute for Water Resources

Estimating USACE Capital Stock 1928 to 2016

2018-R-03

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CDM Federal Programs Corporation
(CDM Smith)

USACE Institute for Water Resources

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This report estimates the capital stock value of USACE water resource infrastructure from 1928 through 2016. The USACE portfolio of Civil Works water resources infrastructure capital extends across the U.S. and provides services and benefits to the nation that support public safety, economic competitiveness, and quality of life. This portfolio of infrastructure capital includes approximately 14,600 miles of levee systems, 715 dams, 13,000 miles of deep draft channels, 12,000 miles of shallow draft channels, over 1,000 harbors, 239 lock chambers, and 75 hydroelectric facilities, with a capacity to generate nearly 24,000 megawatts of electricity. For the purposes of this analysis, the USACE Civil Works water resources investments have been separated into five functional categories: Navigation (including Dredging), Flood Risk Management, Multipurpose, and Mississippi River and Tributaries (MR&T).

Since reaching its peak value of $304 billion in 1982, the USACE capital stock value has been steadily declining and is currently valued at $197 billion. While it appears that the era of investment in water resource infrastructure has peaked and passed, these aging infrastructure investments continue to produce substantial annual benefits. However, the benefit streams currently observed are not sustainable without additional investment in and maintenance of the USACE capital stock.

This report is an update to previous capital stock reports, which were published in 1994, 2003, and 2013 by the USACE Institute for Water Resources. Where possible, this report has made improvements in the methodologies used to study and estimate the value of capital stock.

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Executive Summary

This report presents the findings of a study to update estimates of the ***capital stock value***[1] of water resources infrastructure built by the U.S. Army Corps of Engineers (USACE) from 1928 to 2016. This infrastructure consists of many different types of capital such as dams, levees, harbors and waterway improvements, locks, channels, hydroelectric generating works, and recreation facilities. The portfolio of infrastructure projects provides an annual stream of benefits to the nation in the form of transportation costs savings, flood damages prevented, electric power production, water supply storage, recreation, and ecosystem restoration that contribute to national economic prosperity; global competitiveness; and the health, safety, and quality of life of our citizens. Each year, Federal investments in infrastructure are made that increase capital stock value while the effects of wear and tear, ***deterioration***, and ***retirements*** decrease its value. The capital stock value at any point in time determines the Corps' capacity to produce services for the nation. It is important to monitor the trend in capital stock value as it will ultimately impact the Corps' ability to produce services and benefits in the future. Understanding the Corps capital stock value can also help inform the review and evaluation of requirements for operations and maintenance (O&M) and new investments.

The purpose of this document is to provide reference estimates of USACE capital stock value trends and is intended for use throughout USACE as well as publicly. The USACE capital stock value has been steadily declining since reaching its peak value of $304 billion in 1982, and is currently valued at $197 billion. While it appears that the era of investment in water resource infrastructure has peaked and passed, these aging infrastructure investments continue to produce substantial annual benefits in the $60 to $70 billion range as the recent Value to the Nation Report shows (USACE Institute for Water Resources 2018). The benefit streams currently observed are not sustainable without additional investment in and maintenance of the USACE capital stock. A steady, strong demand placed on deteriorating ***assets*** is going to reach a tipping point where the system cannot meet demands without substantial routine and major maintenance cost increases.

The current study builds upon three prior IWR studies of the value of USACE water resources capital stock, completed in 1994, 2003, and 2013. The 2013 study followed the basic approach of the two earlier studies and estimated the value of USACE water resources capital stock for the years 1928 through 2011 using the ***Perpetual Inventory Method (PIM)*** (USACE IWR 2013a). This method has been endorsed as the preferred approach for estimating capital stock by the ***Organization of Economic Cooperation and Development (OECD)***, the internationally accepted authority on capital measures. The current study builds upon the most recent report, providing estimates through 2016.

This study improves upon the previous study by:

- Employing sensitivity analysis to evaluate critical study assumptions and parameters and provide insights into capital stock value uncertainty, and
- Investigating the possibility of disaggregating USACE capital stock investments according to business lines. Unfortunately, there is insufficient information currently available to accomplish this objective.

[1] Terms and concepts shown in ***bolded italics*** are defined in the glossary found in Appendix A of this report.

Following previous studies, the PIM model implemented in this analysis shows the time series of USACE Civil Works water resources investments in five functional categories: Navigation (including Dredging), Flood Risk Management, Multipurpose, and Mississippi River and Tributaries (MR&T) shown in Figure ES-1. Credible data for the MR&T functional category begins in 1928 and for other functional categories in 1936, coinciding with the Flood Control Act of that year. Between 1936 and 1982, including the dip in funding during World War II (1941 to 1946), the average annual USACE Civil Works water resources investment was a little over $8 billion/yr in 2016 dollars. Since then, annual capital investment has averaged about $4.4 billion. The cumulative effect of these investments is shown in Figure ES-2, with investments over time contributing to the growth in USACE capital stock value through its peak in 1982.

Findings and key points to be drawn from this study are:

- The estimated USACE capital stock value increased $5.6 billion on average each year from 1928 to 1982, when it peaked at $304 billion. From 1982 to 2016, the estimated value decreased on average by a little over $3 billion each year. For 2016, USACE capital stock was estimated as being $197 billion or approximately what it was between 1961 and 1962, representing a 35% decline from its peak in 1982. All values are expressed in 2016 dollars.

- The USACE infrastructure continues to generate benefits that contribute to our nation's safety, quality of life, and economic competitiveness. However, the implication of the declining trend in capital stock value is that USACE's ability to provide these important benefits to the nation will be diminished, requiring substantially more operations and maintenance ***expenditures*** (O&M), ***major rehabilitation***, or some combination.

- If the average annual ***rate of decline*** in USACE capital stock value observed from 1982 through 2016 persists, USACE capital stock will have lost approximately half its peak value by the year 2036, see Figure ES-2.

- Under the current study assumptions, over the next 10 years, about $24 billion of additional investment—or about $2.4 billion annually—will be needed to sustain the capital stock value near its current level (see Figure ES-2). Anything less will result in further decline over that time frame. This would imply over a 50% increase of the USACE annual investments in its capital stock.

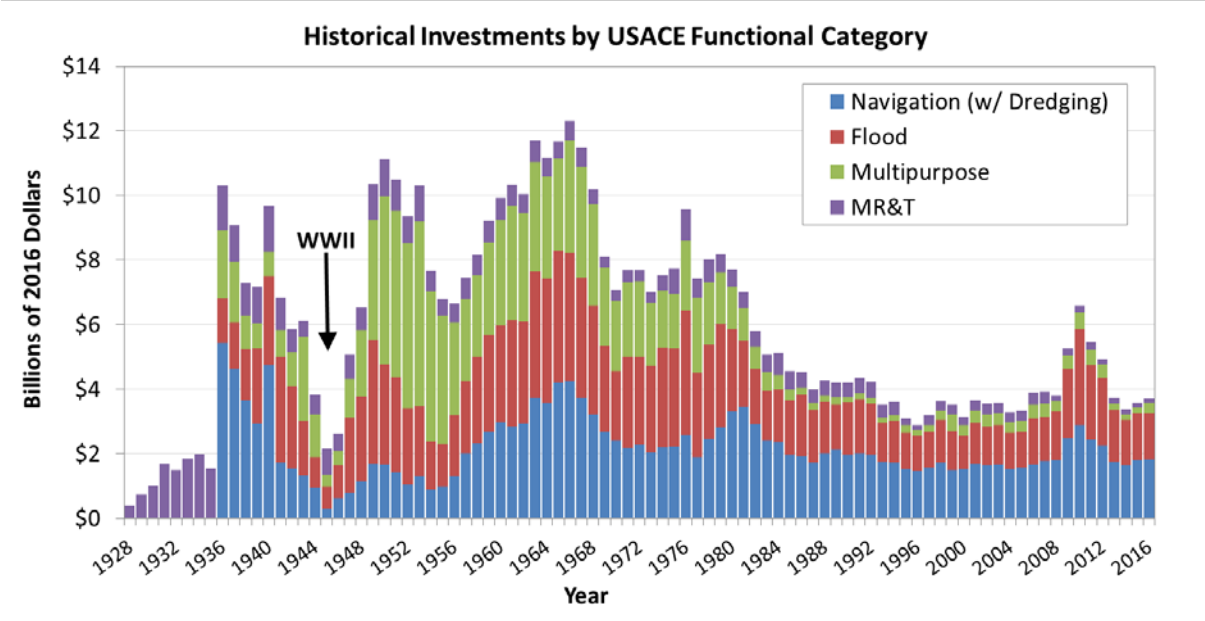

Figure ES- 1
Historical USACE Investments by Functional Category 1928 to 2016

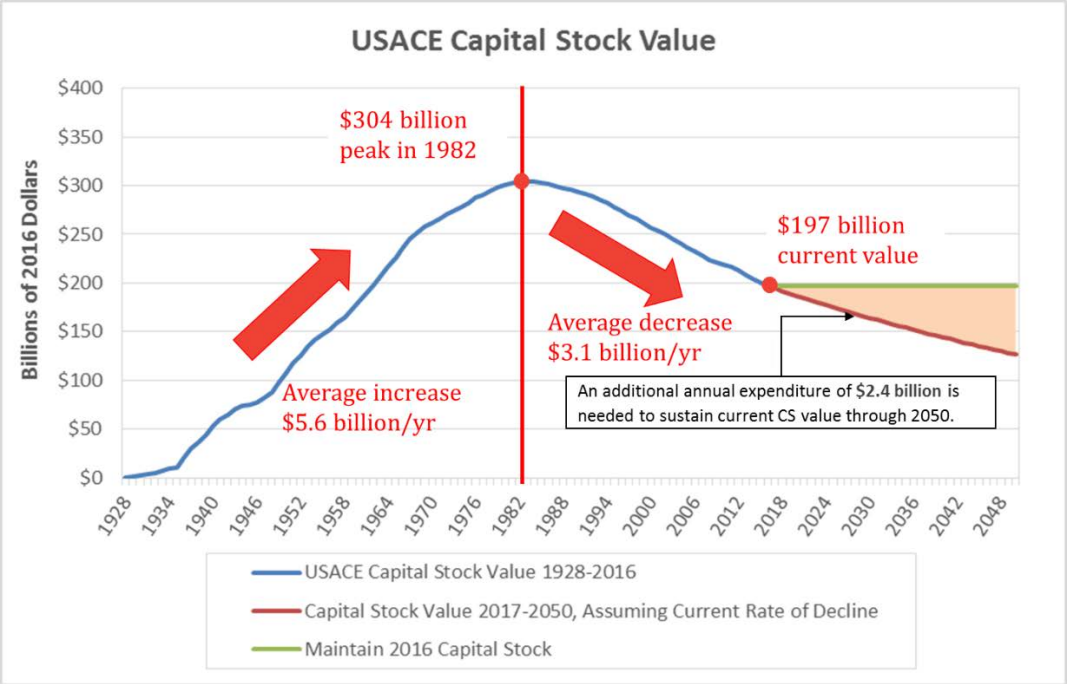

Figure ES- 2
Cumulative USACE Capital Stock value for 1928 to 2016

Issues to consider when interpreting the capital stock values:

The PIM method is a top-down approach to estimating the USACE capital stock values. While this method is the best alternative given the limited data available, the resulting values are surrounded by significant uncertainty. Estimating USACE infrastructure ***service life*** and deterioration rate is very difficult given the large range of structure types, stressors, and construction dates. To address this uncertainty, a sensitivity

analysis was performed on the capital stock value for each mission area for changes in service life and the ***age-efficiency profile*** (i.e., rate and shape of deterioration curve over time). The detailed results are shown in Section 4. These analyses show that final capital stock value is sensitive to both service life and rate of deterioration, resulting in a USACE capital stock value range of $125 to $371 billion. However, regardless of the different assumptions used in sensitivity analysis for both service life and rate of deterioration, this report and all past reports confirm a declining trend in the USACE capital stock value.

Future work and study improvements include:

- Exploring the effects of routine and major maintenance expenditures on the capital stock value,
- Exploring the relationship between deferred maintenance and the capital stock value,
- Working with different districts to evaluate specific project and asset capital stock value trends,
- Continuing to improve data quality and resolution to improve the capital stock value estimates—especially to better understand service life, deterioration, and retirement assumptions,
- Investigating how to better incorporate uncertainty into estimates.
- Further analyzing the relationship between USACE capital stock value and Value to Nation benefits

Section 1
Introduction

1.1 Background

The U.S. Army Corps of Engineers' (USACE) portfolio of Civil Works water resources infrastructure capital[2] extends across the United States, providing services and benefits to the nation that support public safety, economic competitiveness, and quality of life. This portfolio of infrastructure capital includes approximately 14,600 miles of levee systems, 715 dams, 13,000 miles of deep draft channels, 12,000 miles of shallow draft channels, over 1,000 harbors, 239 lock chambers, and 75 hydroelectric facilities, with a capacity to generate nearly 24,000 megawatts of electricity. USACE infrastructure provides water reservoir storage for municipal, industrial, and agricultural purposes and manages recreation projects for approximately 250 million visits per year.

In addition, USACE is involved in environmental mitigation and restoration of the natural functions of ecosystems (U.S. Congress, Senate 2015). Capital, as estimated in this study, includes investments in mitigation for Flood Risk Management, Navigation, Multipurpose, and the Mississippi River and Tributary (MR&T) project, but it does not include investments in ecosystem restoration. Mitigation is designed to reduce damages associated with infrastructure investment.

The portfolio of USACE water resources projects constitutes a stock of capital that provides an annual stream of benefits to the nation. Each year, federal appropriations for USACE infrastructure investment ***expenditures*** add to and sustain Civil Works water resources capital stock (less the effects of wear and tear and retirements of capital ***assets*** from productive service). Benefits derived from water resources infrastructure are realized in the form of navigation transportation efficiencies; flood risk reduction; hydropower availability as a source for energy; recreational opportunities; water supply for municipal, industrial, and agricultural activities; and restored ecosystem values. These benefits contribute to our nation's safety, quality of life, and economic competitiveness.

Ecosystem restoration is designed to improve ecosystem health of areas negatively impacted by past USACE infrastructure investments and other development activities. These ecosystem restoration investments produce countless environmental, social, and economic benefits such as habitat restoration, recreation, and improved water quality. Because ecosystem restoration benefits are currently not measured in monetary terms, their importance is often difficult to quantify and communicate. Given these difficulties, environmental capital is not included in this study to allow for calculation of the monetary return on investment from water resources infrastructure. However, such exclusion does not diminish the importance of ecosystem restoration capital.

Information about USACE water resources capital stock and its potential to sustain benefits is important to provide to the Administration, Congress, stakeholders, and the American public as they make investment and operation and maintenance (O&M) decisions. For these reasons, USACE has estimated the value of its water resources capital stock on several prior occasions and has estimated the "return on investment" measured as the annual monetary benefits derived from the project purposes divided by the value of USACE capital stock. As described more fully below, this current study updates the estimated value of

[2] Water resources infrastructure refers principally to large Civil Works projects, including but not limited to dams, levees, improved waterways and harbors, hydroelectric power generating facilities, reservoirs, improved embankments, seawalls, recreational facilities, and other buildings and structures.

USACE water resources capital stock. Additionally, this capital stock study complements an update of the monetary benefits produced by the USACE water resources infrastructure (USACE 2017).

1.2 Purpose and Objectives

The purpose of this study is to estimate the value of the USACE capital stock so that the need for new investments and other work can be considered and the monetary return can be calculated. Specifically, this report will include the following:

- Update and extend the 2013 Institute for Water Resources Report *Estimating USACE Capital Stock, 1928 to 2011* (USACE IWR 2013a) stock to 2016 and incorporate any advances in the field of capital stock estimation and improvements in the methodology used to estimate capital stock since the 2013 report
- Make a comparison between the market value, replacement value, and the capital stock value of the USACE's existing infrastructure
- Investigate the feasibility of breaking down capital stock categories to a higher resolution such as analyzing inland vs. coastal navigation or having hydropower or water supply as standalone programs instead of grouped into multipurpose
- Present the estimate of capital stock on a constant 2016 dollar basis and compare the results with the 2013 capital stock study
- Relate the findings of the study to the conclusions reached in a companion study[3] (USACE 2018) that updates the monetary benefits to the nation produced by USACE Civil Works water resources infrastructure to demonstrate the economic value of the USACE capital stock
- Provide a computer model and user's guide to facilitate the update of capital stock estimates and return on investment calculations

1.3 Organization of the Report

In addition to the Executive Summary and this Introduction section, this report includes the following sections:

- **Section 2: Methodology** – Introduces key elements and concepts of capital stock estimation and provides a stepwise discussion of this methodology as it was used to estimate the value of USACE water resources capital stock. This section also includes a brief review of past studies that have estimated USACE capital stock.
- **Section 3: Capital Stock Calculations** – Provides a narrative to the calculations performed to estimate the value of the USACE capital stock. Appendix B of this report provides an abbreviated illustration of the capital stock calculation.
- **Section 4: Sensitivity Analysis** – Describes sensitivity of key assumptions and parameters used in the capital stock estimate.

[3] See Value to the Nation of the U.S. Army Corps of Engineers' Civil Works Programs, Estimates of National Economic Development (NED) Benefits and Revenues to the U.S. Treasury for 2015 (2017). This report updates estimates of monetary benefits produced by Corps water resources infrastructure for the year 2015. This report also uses the estimated value of Corps water resources infrastructure derived in the present report as the denominator to estimate the "return on investment" on Corps water resources infrastructure.

- **Section 5: Findings and Conclusions** – Presents findings of the capital stock calculation and sensitivity analysis. The discussion also relates the findings and conclusions about the value of USACE capital stock to conclusions reached in the companion study that estimated benefits produced by the capital stock. Section 5 identifies opportunities to advance capital stock analysis in the future.
- **Section 6: References** – Lists the sources cited or consulted in the preparation of this report.

Three appendices follow the main body of the report:

Appendix A: Glossary – This appendix provides the definition of key terms and concepts used in the report. Terms defined in the glossary are shown in bold and italics when introduced in this report.

Appendix B: Calculation Examples – This appendix discusses an example spreadsheet illustration of the capital stock calculation following the methodology developed for this report. The example shows the capital stock value over time resulting from an initial 5 years of investment. This spreadsheet is similar to the spreadsheet model used to calculate total USACE water resources capital stock value over time except that fewer years of investment are shown to simplify the example.

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Section 2
Methodology

This section introduces key elements and concepts for estimating the value of the USACE capital stock and provides a discussion of the methodology used in this report to estimate the value of USACE water resources capital stock. The glossary in Appendix A of this report provides definitions of terms used in describing the method selected to value the USACE capital stock.

The method employed in this report is the Perpetual Inventory Method (PIM). The PIM estimates the USACE capital stock value by tracking historical USACE capital stock investments, depreciating capital according to specified deterioration rates, updating the results to 2016 prices, and accumulating the results into a total. Although the PIM approach is a widely used and accepted approach, it is only an approximation of the actual value of USACE capital stock. The estimates generated by the PIM should be understood in that context and viewed as order of magnitude estimates of the actual USACE capital stock.

2.1 Prior Studies Estimating USACE Capital Stock Value

This report methodology builds upon three previous studies performed in the last 25 years that have estimated the value of USACE water resources capital stock.

The first was completed in the early 1990s as part of the Federal Infrastructure Strategy Program (USACE 1994c). This study utilized a state-by-state time series of annual USACE ***expenditures*** in four functional categories: Navigation, Flood Control, Multipurpose, and MR&T from 1936 through 1992. Capital stock value was estimated based on these investment flows using PIM. The authors of that report constructed two USACE capital stock series—one based upon the use of a straight-line asset decay pattern and one on an economic or efficiency asset decay pattern. A 50-year service life assumption was applied to each of the four functional categories. The total 1990 USACE capital stock value (in 2016 dollars), estimated by this study was $140.6 billion using the straight-line asset decay pattern and about $228 billion using the economic asset decay pattern. As a comparison, the current study estimates the total 1990 capital stock value to be $293 billion (in 2016 dollars).

The second effort to quantify USACE capital stock value was performed in 2003 (USACE 2003). That study estimated the value of the capital stock through 1999. It also utilized PIM to estimate USACE capital stock value based on historical Construction General (CG) appropriation account new work investment flows for the same four functional categories. A 50-year service life and a hyperbolic ***age-efficiency profile*** with a beta factor (β) of 0.9 were assumed for all functional categories.[4] The hyperbolic age-efficiency pattern was used based on the assumption that Civil Works infrastructure will have high ***productive capacity*** (low deterioration) for a long period of time after it is placed in operation, and experience a greater loss in productive capacity (more deterioration) as the infrastructure ages.

The third study, conducted in 2013, also used PIM, the hyperbolic age-efficiency pattern, and historical USACE CG appropriation account new work investment flows to estimate the USACE capital stock from 1928 through 2011. This study departed from the earlier two studies by using different assumptions for

[4] The definition of these terms can be found in the Glossary in Appendix A of this report. Section 2 of this report provides additional explanation of these terms. For additional detail, please see Organization of Economic Cooperation and Development (OECD) 2009.

service life and pattern of asset decay and included investments in navigation dredging and ***major rehabilitation*** into the estimate.

The 2013 study assumed a 60-year service life for the Flood Risk Management, Multipurpose, and MR&T functional categories, and a 75-year service life for the Navigation functional category as opposed to the 50-year service life assumed for the 2003 study. Additionally, the 2013 study assumed a 15-year service life for Navigation Dredging. The overall pattern of asset ***deterioration*** remained the same (i.e., an increasing rate of deterioration over time); however, a smaller beta factor and longer average asset life worked to prolong asset life in comparison to a larger beta factor and shorter average asset life assumed in the 2003 study.

The 2013 study assumed a hyperbolic age-efficiency pattern with 0.6 beta factors for the Flood Risk Management, Multipurpose, and MR&T functional categories and a 0.5 beta factor for the Navigation functional category rather than 0.9 assumed in the 2003 study. Navigation Dredging was assumed to deteriorate along a straight-line age-efficiency pattern over 15 years. A detailed comparison of the 2011 USACE capital stock value to the 2016 USACE capital stock value estimated for this study is provided in Section 5.2 of this report.

2.2 Capital Stock Value Estimation Methods

The capital stock can be estimated in at least four ways: (1) the market value method, (2) the balance of fixed assets method, (3) the administrative record method, and (4) the perpetual inventory method. In all cases, if the estimates are collected in nominal (current) dollars, which is the most likely case, they can be converted to ***constant dollars*** using deflators. In any case, for historical comparisons across time, capital stocks in constant dollars are clearly preferred.

The first method is to estimate the market value of the capital assets using a replacement cost approach. In this case, value is defined as the nominal dollar cost of replacing the physical inventory of existing assets at today's standards; value is generally determined by a physical inventory where feasible. One version of this method is formally known as Plant Replacement Value and Functional Replacement Value.

Executive Order 13327, signed by President Bush on February 4, 2004, requires federal agencies to report on all owned, leased, and otherwise managed federal real property assets (Federal Register 2004). A component of that report is an estimate of the replacement value of all assets (excluding land and leased assets). The replacement value estimate assumes that the asset will be replaced with a newly constructed asset of the same size at the same location at today's buildings standards and codes (General Services Administration 2016). Pursuant to this executive order and its implementation guidance, USACE annually publishes a report that includes a current estimate of the Plant Replacement Value (PRV) (excluding lands and leased assets) of its capital stock.

The 2016 PRV estimate reported by USACE was approximately $267 billion (USACE 2016b, page 77). Physically surveying the USACE capital stock in a "bottom up" approach would be cost prohibitive; instead, the USACE PRV estimate uses the USACE Real Estate Management Information System (REMIS) to pull data from the USACE Financial Management System for (1) original construction costs; (2) cost to government, which includes overhead costs; and (3) any additions and betterments. The data include both dates and costs. REMIS then evaluates the data element called "Feature Code," which is also referred to as Asset Category and calculates the PRV based on inflation factors from Engineer Manual (EM) 1110-2-1304, Civil Works Construction Cost Index System (CWCCIS), and the data in (1) and (2) above. Deflators from EM 1110-2-1304, which is developed and updated semi-annually by the USACE Cost Engineering Center of Expertise, are used to convert the historical nominal dollar investments to constant dollars. Therefore, while the 2016 PRV ($267 billion) represents the current best estimate of replacing all existing USACE

infrastructure, the 2016 capital stock value ($197 billion) presented in this report represents the current value of the existing USACE infrastructure. Monitoring trends in existing capital stock value and current benefits can help USACE to determine when it is time to invest in new structure. As infrastructure ages, it deteriorates, increasing the risk of service loss and increased O&M costs. Therefore, investment in new infrastructure should be made at the point at which the estimated benefits minus O&M costs outweigh the estimated replacement cost.

The second method is the "balance of fixed assets." This method combines occasional surveys of the nominal value of assets with an estimate of inflows and outflows. Correctly applied, this method is an ideal form of PIM—ideal because it substitutes actual retirements for the assumed retirements used in the conventional PIM. This method was eliminated from further consideration due to the lack of available data on the inflow and outflow of capital assets.

The third method is the "administrative records method." It estimates nominal dollar capital stocks using administrative records on the numbers of assets together with available prices. If stock estimates can be based on administrative records, the margin of error for the total stock estimates is considerably reduced. This method was eliminated from further consideration due to the lack of a sufficiently robust administrative record.

The fourth method is PIM. It generates an estimate of the capital stock by accumulating past purchases of assets over their estimated service lives. The standard, or traditional, procedure is to use PIM to estimate the constant dollar net capital stock by first estimating the gross capital stock by accumulating deflated investments and then subtracting deterioration and retirements to obtain a constant dollar productive capital stock.[5]

2.3 Perpetual Inventory Method

The current study builds upon the 2011 estimate to construct constant dollar estimates of the productive capacity of capital stock. It uses PIM and deflated historical USACE CG expenditure data on new work investment, dredging, and major rehabilitation to estimate the 2016 value of the USACE constant dollar capital stock. The nominal dollar expenditure data are deflated by the Engineering News Record Construction Cost Index. Service life and pattern of asset decay have been incorporated into the estimate, and the sensitivity of the results to different service life and decay pattern assumptions have been tested. The current study assumes a hyperbolic age-efficiency pattern with a beta factor of 0.6 for the Flood Risk Management, Multipurpose, and MR&T functional categories; 0.5 for the Navigation functional category; and a 15-year straight-line age-efficiency pattern for Navigation dredging. Additionally, the current study assumes a 60-year service life for the Flood Risk Management, Multipurpose, and MR&T functional categories; a 75-year service life for the Navigation functional category; and a 15-year service life for navigation dredging.

PIM achieves the objective of estimating the value of capital stock by calculating the cumulative value of investments over time, adjusting for asset retirements and losses in productive capacity caused by deterioration (i.e., normal wear and tear[6]).[7] Retirements and deterioration are further explained as follows:

[5] See OECD 2009.

[6] Normal wear and tear simply refers to the loss of productive capacity over time as a result of an asset performing its intended purpose. The term is predicated on the understanding that assets do not perform at 100% of their productive capacity in perpetuity and some level of diminished productive capacity is realized over time despite normal maintenance.

[7] A detailed discussion and additional background on PIM is contained in *Measuring Capital: OECD Manual Second Edition, 2009*.

- Retirements are expressed by a retirement profile (i.e., a model of the retirement process of assets over time), which is defined by the service life (i.e., the age when an asset has exhausted it productive capacity), and an assumed deterioration function which is used to model the pattern by which capital stock is retired from the portfolio.
- Deterioration is expressed by an age-efficiency profile, which describes the pattern and rate at which an asset's productive efficiency deteriorates over time.

Each of these PIM components and the assumptions about them used for estimating the value of USACE water resources capital stock is described in the following section.

PIM is the method preferred by the ***Organization of Economic Cooperation and Development***[8] ***(OECD)*** and the ***U.S. Bureau of Economic Analysis (BEA)*** to calculate the productive measure of capital, including water resources infrastructure. The measurement exercise is one of inferring a capital stock value from a stream of current and past investments (Hulten 1990). Except for Korea, Japan, and the Netherlands[9], which have performed surveys of capital stock involving site visits by enumerators, all other OECD countries utilize PIM for their capital stock estimates (Blades 2001). PIM is well-suited for situations where the quantity of new capital added each year (i.e., investments) can be identified but where, because of its quantity and diversity, the physical condition of the stock of existing infrastructure cannot be readily or economically evaluated. In these circumstances PIM has become the recognized approach for calculating the productive measure of capital when time and budget constraints make it difficult or impossible to perform a detailed, ground-level inventory and enumeration of an entity's capital stock portfolio (OECD 2009).

2.4 Assumptions

This section provides a discussion of the PIM components and assumptions used for this analysis. It builds upon some of the key terms and parameters presented above.

The following equation depicts the PIM methodology discussed above using the terms introduced in this section. The estimate of net capital stock using the PIM is defined as:

$$NCS_t = \sum_{t=0}^{T} \sum_{i=0}^{C} (I - R - D)_{i,\, T-t}$$

Where:

NCS_t = Net capital stock for year t
T= Analysis period – determined based on the point in time USACE began constructing Civil Works assets and available data
C = Asset Group – determined based on the USACE capital stock inventory
I = Investments – determined by historical USACE "new work" investment
R = Retirements – determined by the service life assumption for the USACE capital stock inventory
D = Estimated deterioration – determined by the assumed β

2.4.1 Investments

The investment data for deriving the estimate of USACE water resources capital stock focused on the USACE Civil Works CG and MR&T appropriations accounts. Appropriations for the Navigation, Flood Risk

[8] The OECD was founded in 1948 to stimulate economic progress and world trade.

[9] Only the Netherlands performs capital stock surveys on a regular basis, with different subsectors covered each year and estimates derived using a 5-year "rolling benchmark" method.

Management, and Multipurpose functional categories come from CG while the MR&T appropriations are authorized separately under the MR&T authority.[10] Dredging functional category appropriations are categorized under operations and maintenance. The functional categories for which capital stock estimates are derived in this analysis are:

- **Navigation** – The USACE Navigation Mission is to provide safe, reliable, efficient, effective, and environmentally sustainable waterborne transportation systems for movement of commerce, national security needs, and recreation (USACE 2012b). For the purposes of this study, CG appropriations supporting the aforementioned mission are classified under the Navigation functional category. Navigation investments include but are not limited to inland waterway system (harbors, channels, locks and dams, coastal [deep and shallow draft] and Great Lakes harbors and channels).

- **Dredging (Navigation)** – USACE conducts periodic dredging of Navigation inland and coastal waterways to allow for the safe and reliable movement of vessels. The Dredging functional category differs from the other functional categories in that it is an improvement made to existing infrastructure designed to extend the useful life of a given asset. In this case, the asset is an improvement made to an engineered channel. Using this logic, it then follows that dredging maintenance costs can be considered capital expenses and should be included as capital assets in the PIM calculation. It should be noted that within the PIM, the Dredging functional category capital stock value is derived using a set of assumptions that is separate and different from the other four functional categories because of the aforementioned differences. These improvements are assumed to have a shorter average service life because their level of service deteriorates at a faster rate compared to the other four functional categories. Because dredging serves to extend the life of Navigation projects, it is also included in the Navigation analysis presented in Section 3.2.1. In addition, because dredging also follows a very different deterioration pattern than the other functional categories, its related methodologies and capital stock values are respectively reported in Sections 2.5.6 and 3.2.5.

- **Flood Risk Management** – A primary mission of USACE is to support flood risk management activities of communities in both urban and rural areas throughout the U.S. To carry out this mission, USACE constructs and operates projects that reduce flood risk and the risk of loss from costal storms and conducts emergency management activities. For the purposes of this study, CG appropriations supporting the aforementioned mission and activities are classified under the Flood Risk Management functional category. Flood Risk Management investments include but are not limited to dikes, levees, dams, reservoirs, and measures to reduce losses from coastal storms.

- **Multipurpose** – Some USACE Civil Works water resources infrastructure provides benefits related to more than one project purpose. For instance, a dam and reservoir may provide flood risk reduction benefits, electricity generation, and water supply storage. Therefore, this dam is an example of an infrastructure item serving multiple purposes. For the purposes of this study, CG investments supporting more than one purpose are classified under the Multipurpose functional category.

- **MR&T** – The USACE MR&T project was authorized by the 1928 Flood Control Act. Its purpose is to serve as a comprehensive, unified system of public works within the Lower Mississippi River Valley to provide protection from floods and an equally efficient navigation channel (USACE 2009). MR&T is a USACE Civil Works appropriation account unto itself. Thus, MR&T investments used for this

[10] The MR&T appropriation funds new construction, operations, and maintenance for projects authorized under the MR&T authority. New work for MR&T appropriations is funded under the MR&T construction account.

analysis do not originate from the USACE Civil Works CG appropriation account. Rather, within the MR&T appropriation account, appropriations are allocated to an MR&T construction account. These funds represent the investments used in deriving the MR&T capital stock estimate for this analysis. These investments include but are not limited to improvements to coastal harbors and inland waterways and improvements at dams and levees along the MR&T system.

- **Maintenance and Major Rehabilitation** – The treatment of repairs and maintenance is a grey area in capital stock measurement. Lives of assets that are becoming obsolete may be deliberately shortened by neglecting repairs and maintenance. Conversely, major repairs or renovations which are not included in major rehabilitation may be employed to prolong the lives of important assets beyond their expected service lives. Similarly, expenditures that enhance the performance or capacity of assets are treated as additions to the capital stock. A component of the capital stock that has not been given adequate maintenance throughout its service life will deteriorate at a faster rate than a component that has received substantial preventative maintenance. Thus, the service lives will vary depending on the piece of equipment and the amount of upkeep it has received. OECD has concluded that more guidance might be provided on the theoretical and operational criteria that may be used to distinguish ordinary repairs and maintenance from expenditures that count as gross ***fixed capital*** formation.[11] We will continue to include major rehabilitation expenditure in the capital stock estimate, but we assume regular maintenance to be included in the age-efficiency profiles chosen to represent deterioration. Some assets may not receive enough maintenance, shortening their service life, while other assets may receive extra maintenance, which would extend their service life. In view of the uncertainty regarding the role of maintenance in valuing capital stock, we also test the sensitivity of alternative assumptions related to asset service life, and rate and temporal pattern of deterioration by evaluating different service life durations, age-efficiency profile types, and rate of decline values.

Cumulative investments in new work for the functional categories of Navigation, Flood Risk Management, and Multipurpose are for the years 1936 through 2016. For MR&T, cumulative investments span the years 1928 through 2016. For Dredging, cumulative investments span the years 1963 through 2016 (years for which credible data are available).

2.4.2 Major Rehabilitation

USACE defines a major rehabilitation program as a capital expenditure for reliability or efficiency improvement (USACE 2011b). Program projects consist of structural or mechanical work on USACE-operated facilities such as locks, dams, and hydropower plants. Rigorous technical and economic analyses are performed to justify capital expenditures for these projects. The investments in major rehabilitation serve to restore infrastructure performance, extending their service lives such that the infrastructure is restored to an improved level of service.

Prior to fiscal year (FY) 1993, "major rehabilitation" work to refurbish and renew aging projects was funded out of the Operations and Maintenance account. Since the beginning of FY 1993, such work has been funded out of the CG account (USACE 2011b). Therefore, it is understood that the available USACE expenditure data used to calculate capital stock value does not account for major rehabilitation expenditures before FY 1993. Consequently, additional data identifying major rehabilitation expenditures prior to calendar year 1994 were sought to account for these expenditures' contribution to the capital stock value over time.

[11] See OECD 2009.

USACE investment in major rehabilitation is accounted for in this study in the CG new work expenditures input of the PIM model. As mentioned above, these investments are already included in the construction general new work expenditures from 1994 through 2016.

To account for the impact to capital stock value from prior major rehabilitation investments, CDM Smith obtained historical major rehabilitation expenditure data from USACE dating back to 1977. These data include an identifier for the functional category receiving the major rehabilitation funding. Therefore, for the years 1977 through 1993, the major rehabilitation investments could be directly added to expenditures by functional category in the PIM spreadsheet model.

The relationship of major rehabilitation expenditures to total CG new work expenditures for years of available data (1977 through 1993) was used to estimate major rehabilitation expenditures prior to 1977. The actual and estimated major rehabilitation investments are added to their respective CG new work functional categories within the PIM spreadsheet model for the years 1936 through 1976 based upon this relationship.

2.4.3 Asset Service Life and Retirement

The retirement age (i.e., service life) of a single investment is the age at which that investment is removed from service, representing the end of its service life. An age-efficiency profile models the deterioration of that investment from its initiation to the end of its service life. The investment's productive capacity is decreased each year as a function of its age-efficiency profile as the investment matures.

Service Life

The service life assumption refers to the age at which all the investments in the portfolio are assumed to retire. The service lives defined below differ from the period of analysis used in USACE feasibility studies. For planning purposes USACE uses a period of analysis defined in the Water Resources Council's "Principles and Guidelines" as the period over which any alternative plan would have significant beneficial or adverse effect. Specifically, a period not to exceed 50-years except for major multiple purpose reservoir projects, or a period not to exceed 100 years for major multiple purpose reservoir projects are used. The period of analysis used in planning studies is an analytical tool used to compare project benefits and costs over time while the service life estimates used in this report are empirical estimates derived from the actual service life performance of the USACE infrastructure.

For the purposes of this study and under the framework of the PIM model, which requires a single retirement age for each USACE functional category, the service life is the assumed age at which investments will be removed from the estimated USACE capital stock portfolio. The service life assumption considers all the factors that could cause these investments to be retired from the capital stock portfolio. These include:

- Normal wear and tear that exhausts the productive capacity of an asset
- ***Recapitalizations*** where substantial new capital has been expended on an existing asset to the extent that its life-cycle clock has been effectively restarted
- Assets retired from the service due to obsolescence or in cases where the economics related to the asset do not warrant continued operations
- Assets that have catastrophically failed due to natural or manmade events

It should be noted that within the USACE PIM model, a single service life (i.e., retirement age) assumption is applied independently to each functional category. This means that, for the purposes of this study, all investments within a particular category deteriorate over time and are removed from service at their

assumed service life age. The service life assumption for each functional category used in this study was established by examining the current age of USACE water resources projects and a review of authoritative sources on the subject.

Common sources for estimating service lives include asset lives prescribed by tax authorities[12], company accounts, statistical surveys, capital goods producers, administrative records, expert advice, and other countries' estimates (Blades 2001). Meinen et al. (1998) state that arriving at an accurate service life assumption is usually the most difficult aspect of performing the PIM. Given these difficulties, service life is one of the model parameters that will be subjected to a sensitivity analysis later in this report.

Table 1 presents a simple tabulation of the age of USACE projects by functional category. Ages by functional category shown in Table 1 consist of projects identified in the Chief of Engineers Annual report and in internal USACE data files. In this table, lock chamber and dam age statistics are presented for multiple functional categories including navigation (both lock chambers and dams), flood risk management (both single and multipurpose), and multipurpose (with and without flood risk management). A more in-depth analysis of current infrastructure age is also included as part of the sensitivity analysis on service life in Section 4.3.

This report classifies projects under the categories of Navigation, Flood Control, and Multipurpose.[13] It is important to note that these average ages are chronological ages representing the number of years since being placed in service. The average, chronological age is not directly analogous to the average service life because it does not include asset retirements and removals, or major rehabilitation expenditures. However, the age of existing assets is useful in performing a descriptive statistical comparison of functional categories to understand similarities and differences that may inform the service life assumption.

Table 1: Average Age of USACE Water Resources Projects (Snorteland 2017; Riley 2017)

Functional Category	Number of Projects	Average Age	Median Age	Standard Deviation	Minimum Age	Maximum Age
Flood Risk Management (FRM) Reservoirs	135	59	59	14.3	7	81
Navigation Dams	71	70	78	27.1	13	181
Navigation Lock Chambers	222	63	58	26.6	8	178
Multipurpose (with FRM)	389	57	54	18.5	16	133
Multipurpose (without FRM)	120	61	53	29.4	6	178
Multipurpose (ALL)	509	58	54	22	6	178
All Dams excluding single purpose NAV	644	58	55	20	6	178

Prior USACE capital stock estimates used a 50-year service life assumption for all functional categories (USACE 1994c; USACE 2003). BEA has developed service life estimates for government nonresidential structures that account for asset retirements and removal from service. These estimates are published in the BEA 1999 report *Fixed Reproducible Tangible Wealth in the United States, 1925-94*. In this report, BEA shows service life assumptions for government infrastructure as follows in Table 2:

[12] For example, in the 1940s and 1950s, the Internal Revenue Service's Bulletin F provided useful life estimates for over 5,000 assets and provided methods for computing their depreciation rates (Internal Revenue Service 2008).

[13] It is assumed that MR&T projects are interspersed among these categories of projects but they could not be identified.

Table 2: BEA Service Life Estimates for Government Nonresidential Structures

Asset	Service Life (years)
Buildings:	
Industrial	32
Educational	50
Hospital	50
Other	50
Non-buildings:	
Highways and Streets	60
Conservation and Development	60
Sewer Systems	60
Water Systems	60
Military Facilities	50
Other	60

As shown in Table 2, BEA estimates for "Non-buildings" generally use an asset service life of 60 years. These categories of infrastructure approximate the kind of large infrastructure projects represented by USACE water resources infrastructure projects; thus, it seems more realistic to apply a 60-year service life assumption for USACE water resources infrastructure, excluding dredging projects. However, as suggested by the distribution of project ages shown in Table 1, Navigation infrastructure has a higher average age (63 years for lock chambers and 70 years for navigation dams) compared to the other functional categories (58 years for all multipurpose dams and 59 years for single purpose flood projects). Median values also suggest the central tendency of navigation infrastructure age (78 years for dams and 58 for lock chambers) is notably higher than that of dam infrastructure (54 years for all multipurpose dams and 59 for single purpose flood projects). The second to last row (Multipurpose (ALL)) in Table 1 presents the age distribution statistics related to all dams authorized for multiple purposes. Similarly, the last row in Table 1 shows the age distribution for all dams (multipurpose and single purpose) excluding single purpose navigation dams. Both flood and multipurpose dams have similar age distributions. While these Corps infrastructure age statistics only communicate current Corps structure age and do not correspond to structure service life, they can be used as a proxy for determining the relative service lives associated with different infrastructure types. Within the Corps, Navigation projects are generally older than projects in other functional categories. Therefore, this study estimates a 75-year service life assumption for the Navigation functional category and a 60-year service life assumption for all other functional categories excluding Dredging. Dredging projects have a much shorter service life compared to other functional categories. Information regarding the number of USACE dredging projects and their average age was not available for this analysis. As discussed in Section 2.5.6 below, a separate, shorter assumption for service life is applied to the Dredging functional category.

An additional factor contributing to uncertainty in service life estimates is the impact of climate change on asset wear and tear. A changing climate and rising sea levels have the potential to reduce the resiliency of the USACE infrastructure and reduce project service life for project's not designed with climate change in mind. This is particularly true for older more mature projects, but these projects are closer to the end of their service lives and the period of time over which they can be impacted is shorter. A sensitivity analysis reflecting the impact of reducing service life is included later in the report in section 4.3.

Service Life Summary

The retirement profile utilized for this study consists of the following assumptions:

1. All capital investments in the USACE Civil Works portfolio are assumed to retire when they reach the end of their service life.

2. All capital investments in the same functional category are assumed to have the same service life.

These assumptions work together to form the estimated service life of USACE Civil Works investments as employed in the PIM spreadsheet model. The following section discusses how asset efficiency (i.e., level of service) is dealt with using the PIM spreadsheet model developed for this study.

2.4.4 Estimated Deterioration

Age-Efficiency Profile

The age-efficiency profile describes the time pattern of deterioration in productive capacity of a capital stock investment (OECD 2009). Productive capacity refers to an investment's ability to perform at its originally intended level of service. Typically, the age-efficiency profile is expressed in relation to the productive capacity of a new investment (i.e., at x years of age, the asset is y percent as efficient as a new asset) (OECD 2009). Over the life of an investment, its productive capacity will degrade due to assumed wear and tear of the physical asset being represented by the investment. The age-efficiency function used for an investment is calculated to approximate the actual productive capacity of the asset over time. Within the PIM method, regular maintenance is assumed to occur. Therefore, any deterioration modeled is due to asset aging, not lack of maintenance.

The age-efficiency profile seeks to simulate this deterioration pattern over a portfolio of assets. Essentially, the age-efficiency profile calculates the probability that a certain portion of the portfolio will have a capital renewal requirement without having to specifically define or locate the requirement. Four mathematical functions are most often used to approximate this demand for capital renewal (i.e., loss of productive capacity): hyperbolic, linear, geometric, and One-Hoss Shay.[14]

Based on simple asset observations and the premise behind PIM, Civil Works infrastructure will have high productive capacity (low deterioration) for a long period of time after it is placed in operation and experience a greater loss in productive capacity (more deterioration) as the infrastructure ages. Thus, as in prior USACE capital stock estimates, this study utilizes the hyperbolic function, which matches this deterioration trend. In contrast, the geometric function assumes that productive capacity decreases more rapidly at the start of an asset's service life, slowing as it ages, which does not match typical USACE asset deterioration patterns.

Together with the service life assumption and the ***simultaneous exit mortality assumption*** described above, the PIM model utilized for this study assumes asset efficiency deteriorates over time according to the hyperbolic pattern of deterioration until it reaches its assumed service life age at which point the investment is retired. Further discussion of the application of the hyperbolic function in estimating the USACE capital stock value for this analysis can be found in Section 3 of this report.

[14] See Hulten and Wykoff (1981) for a discussion of age-efficiency profiles.

Hyperbolic Function

Hyperbolic functions can be used to approximate a wide variety of age-efficiency patterns, and those with a β greater than zero are concave in shape (See Figure 1).[15] A concave hyperbolic function is used to model assets that lose little productive capacity during the early stages of their service lives (i.e., slow decay of efficiency) but experience rapid loss of productive capacity toward the end of their service lives. For this study, β is assumed to be 0.6 for the Flood Risk Management, Multipurpose, and MR&T functional categories. This value is approximately the midpoint between 0.5 and 0.75, the range recommended by OECD (2009). The β for the Navigation functional category is assumed to be 0.5, the range minimum, due to its unique lifecycle characteristics that are heavily impacted by sedimentation, requiring periodic dredging to extend overall asset service life.

The formula for the hyperbolic decay function is:

$$G(t) = \frac{(T - t)}{[T - (\beta \times t)]}$$

Where:

G(t) = Productive capacity in year t (decay function)
T= Analysis period
t = Year of analysis (t= 0 to T)
β = Factor that shapes the hyperbolic decay function (0 <= β <=1)

The higher β, the more productive an asset is in any given year of the asset's life. Figure 1 shows how the shape of the age-efficiency profile changes based on beta factors of 0.0, 0.5, 0.6, and 1.0.

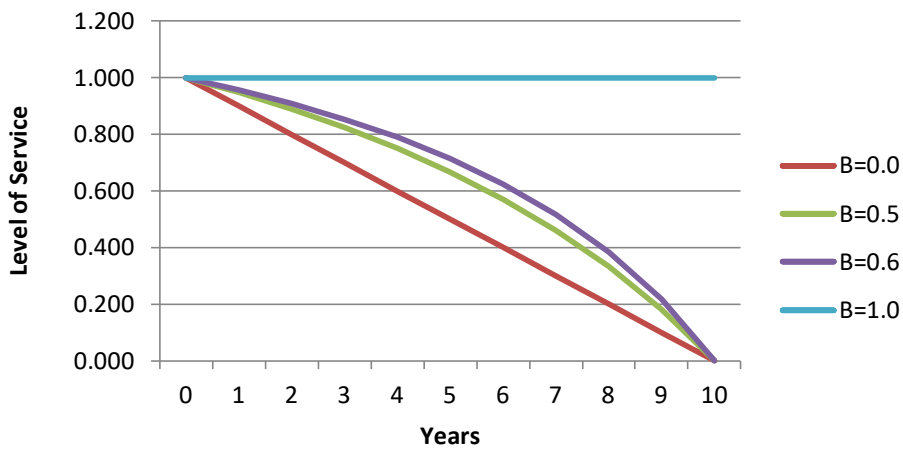

Figure 1
Hyperbolic Age-Efficiency Profiles

[15] β shapes the hyperbolic decay function as indicated in Figure 2. See the OECD Manual 2009 for additional information regarding the application of β in PIM.

Types of Hyperbolic Functions

Straight-line (Linear) Function

A straight-line (linear) pattern assumes assets lose a fixed amount of productive capacity every year of their service life (see Figure 2). Using this function, loss of productive capacity is calculated as $1/N$ where N represents the asset's service life. The straight-line pattern is equivalent to a hyperbolic pattern with a beta factor of 0.0. The linear function was used to represent the age-efficiency profile for dredging to simulate the average sedimentation process over all navigation projects throughout USACE.

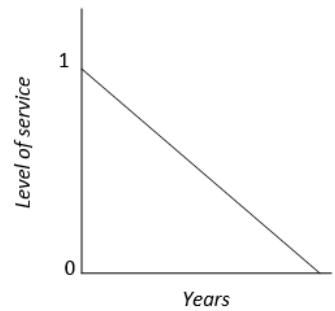

Figure 2
Straight-line Age-Efficiency Profile

One-Hoss Shay Function

The One-Hoss Shay age-efficiency profile represents a pattern whereby assets maintain their full productive capacity up until the moment they reach the end of their service life (i.e., no deterioration until retirement). At this point, the asset is retired. The example of a light bulb illustrates the One-Hoss Shay function concept. A light bulb does not exhibit deterioration in productive capacity over its lifespan. Rather, it emits a steady source of light up until it suddenly burns out. The One-Hoss Shay function is depicted in Figure 3. As the figure shows, the One-Hoss Shay age-efficiency profile also exhibits a simultaneous exit mortality assumption. The One-Hoss Shay age-efficiency profile is equivalent to a hyperbolic age-efficiency profile with a β of 1. In some instances, the One-Hoss Shay function could be representative of individual project deterioration (e.g., a levee may perform at its productive capacity until it fails under extreme conditions). However, it was not deemed appropriate for the current study's use in which all USACE assets are evaluated together. It is very unlikely, for example, that all navigation projects will perform at their productive capacity for the same period and all fail at the same time. When evaluating the USACE capital stock at the business line level, it is much more likely that different assets will deteriorate and be rehabilitated at different times and rates.

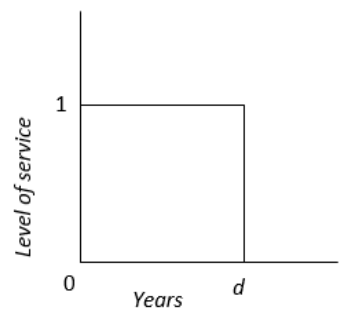

Figure 3
One-Hoss Shay Age-Efficiency Profile

Geometric Function

Geometric functions assume that productive capacity decreases at a constant rate or percent each year over an asset's service life. In real terms, this means the absolute loss in value is greater in the earlier years of service life than in the later years (see Figure 4). This pattern is generally opposite of the concave hyperbolic patterns, which exhibit a slow deterioration at the beginning of the service life and rapid deterioration at the end of the service life. Because USACE assets are generally observed to deteriorate more rapidly closer to the end of their service life rather than at the start of their life, the geometric function was deemed inappropriate in the current study.

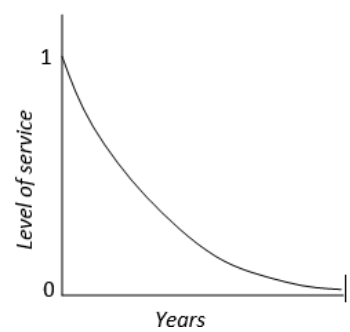

Figure 4
Geometric Age-Efficiency Profile

The equation for the geometric function is:

$$G(t) = (1 - r)^t$$

Where:

G(t) = Productive capacity in year t (decay function)
T= Analysis period
t = Year of analysis (t= 0 to T)
r = Factor that shapes the geometric decay function (0 <= r <=1)

2.5 Other Considerations

2.5.1 Use of Constant or Nominal Dollars

Using ***constant dollars*** expresses all monetary figures based on a fixed point in time, such as the present or a defined base year. Calculations using constant dollars adjust for inflation. Using ***nominal dollars*** on the other hand does not adjust for inflation or reduced buying power. Consistent with previous reports, this report uses constant dollars, using 2016 as the base year. The Engineering News-Record Construction Cost Indexes (Engineering News Record 2016) is used to adjust dollar values to constant 2016 dollars.

2.5.2 Beginning Date for the Calculation

A critical consideration in PIM is the beginning date of the calculation and the corresponding capital stock value at that point in time. Calculations performed in the 1994 capital stock analysis assumed this value was zero starting in 1928. Problems with this assumption are noted in the 2003 USACE report.[16] In that report, the authors recommended that PIM should be implemented with a capital benchmark based on USACE's estimate of the adjusted ***book value*** for 1928 or the earliest year for which a reliable book value is available. Available data are insufficient to determine the age and value of the capital stock portfolio by functional category prior to 1928 for MR&T and 1936 for the other functional categories. Therefore, this study will make the same assumption as prior reports that the value of capital stock for each functional category is zero at the beginning of the base year, 1928.

2.5.3 Financial Data Considerations

There are several specific considerations related to the use of available financial data. These considerations are generally related to differences in accounting methodologies used during different periods.[17] Therefore, special care has been taken to ensure consistent definitions and practices were used throughout the period of analysis. However, given the complexities and subtleties surrounding data categorization, data reliability is considered a source of uncertainty in the calculation of USACE capital stock value. Section 5.5 of this report provides further discussion of data limitations encountered in this report.

2.5.4 Problems with Aggregated Data

Problems using aggregated data are recognized in the 2003 USACE report, *Estimating a Productive Measure of Corps Capital Stock.* Briefly these included:

- Within a given functional category, there may exist a wide range of asset types. For example, within navigation, there are locks, dams, and channel assets. Each type of asset may have a different service life and a different age-efficiency profiles. Despite these differences, the aggregate nature of the USACE investment data requires that the service life and age-efficiency profile assumptions be

[16] The 2003 USACE report identifies the assumption of a USACE productive capital stock of zero prior to 1928 as one of three assumptions that might reasonably be changed with improved data.

[17] For example, USACE funded major rehabilitations of its infrastructure from its operations and maintenance account prior to 1994 and then moved funding of such major infrastructure recapitalizations to its CG account.

applied uniformly within each of the functional areas. Therefore, within navigation, locks, dams, and channels are assumed to have the same service life and to deteriorate at the same rate.

- The aggregate nature of the USACE investment data dictated that the primary analysis of USACE capital stock investments be categorized into the five functional areas described above: navigation, flood risk management, MR&T, multipurpose, and dredging. In recent years, USACE has collected data by business line (e.g. inland navigation, coastal navigation, flood damage reduction, recreation, water supply, and hydropower). Corresponding business line level budget request data are available starting in 2008. However, the availability and quality of business line level expenditure data are still being verified and therefore not usable for the current study.

- The fundamental issue with aggregating data is maintaining the integrity of scale when rolling up information and assumptions. Applying inventory-wide assumptions to aggregated data comprised of multiple functional areas with infrastructure serving multiple functions and purposes is not well-suited for communicating the unique characteristics of the USACE inventory. It is recognized that this issue could be amended with data that allow for finer disaggregation both of inventory subsets (e.g., flood risk management, levees vs. dams) and business lines (e.g., within Multipurpose, disaggregate recreation, water supply, and hydropower).

2.5.5 Concepts of Deterioration versus Depreciation

This section provides a brief discussion of the deterioration versus depreciation and the applicability of each in deriving the USACE capital stock estimate. Fundamentally, depreciation is a financial concept designed to match revenue and expenses. An asset purchased in one year generates revenue over multiple years. Therefore, the purchase is also spread or expensed over several years. This expense is called depreciation. The statement of financial position shows the purchase price of the asset less accumulated depreciation. By contrast, deterioration focuses on performance rather than financial value. When an asset deteriorates, performance is negatively affected, reducing an asset's productive capacity.

The report titled *Estimating a Productive Measure of Corps Capital Stock* (USACE 2003) provides an excellent discussion of the competing concepts applying deterioration versus depreciation in a capital stock analysis. This point is unsettled by OECD (2009), and this study accepts and adopts the points made in the 2003 USACE report. Specifically, the concept of deterioration is applied to the analysis of USACE capital stock and governs the use of the age-efficiency profile determination of each functional category. The outcome is the estimation of an age-efficiency profile function that will be limited to the hyperbolic form with a concave shape.

2.5.6 The Case of Dredging

Dredging represents a special case when it comes to capital stock valuation and PIM. Generally, capital stock flows fit neatly into the category of manmade structures. Dredging represents an improvement to maintain an excavated channel and does not fit as neatly into the concepts underpinning the PIM. This is compounded by the practice that USACE classifies all dredging after the initial dredge as a maintenance expense for accounting purposes. Alternatively, a case can be made that all dredging costs can be considered a capital expense for the purposes of PIM analysis. This argument is supported by opinions stated by the British Institute of Engineers defining capital dredging as, "that which involved capital expenditure, the removal of previously undisturbed geological material or recurrent dredging with a periodicity in excess of three years" (Institute of Civil Engineers 1991).

An initial dredge makes a manmade improvement to a land feature, providing a benefit that will degrade in a relatively short period of time due to natural forces. Most dredged areas will silt-up or the channel sides will slump, eventually limiting channel capacity. The mode of degradation is different, but the effect (i.e.,

loss of productive capacity) is the same as is realized from an aging manmade structure. Resetting the productive capacity of a manmade structure at the end of its service life is a capital expenditure. Using this logic, follow-on dredging is also considered a capital expenditure. In this way, incorporating dredging into the analysis is in keeping with the intent of PIM and the understood purpose of this study and therefore is included as an improvement.

Due to natural processes that impact the useful life of a dredged waterway, dredging cannot generate services (e.g., safe and reliable navigable waterways) for a period of time comparable to manmade infrastructure such as dams and levees. Thus, the service life and pattern of deterioration assumptions for dredging are different than those of the infrastructure that falls into the other four functional categories. As a result, dredging capital stock value is calculated using PIM assumptions unique to that functional category. We have chosen to develop the PIM using a straight-line deterioration method (see Figure 2) and a 15-year service life for the Dredging functional category. These assumptions have been chosen because dredging-related capital improvements have a shorter lifespan than more durable assets such as dams and levees. Straight-line deterioration has been assumed on an experiential basis as presently there is no empirical evidence available to more precisely determine depreciation patterns. These differing assumptions have several key impacts on the PIM analysis. The first is that assets in the Dredging functional category decline in level of service at a more rapid rate from year to year compared to assets in the other four functional categories. When using a hyperbolic function and 60-year service life, assets deteriorate at less than 1% on average over the first 15 years of useful life and never more than 4% in any year. Comparably, in the dredging analysis, assets decline at 6.25% annually. Additionally, because of a shorter life span, investment must be replenished at a faster rate to maintain capital stock levels.

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Section 3
Capital Stock Calculations

This section provides a narrative to the calculations performed in the accompanying Microsoft Excel workbook using the methodology described in Section 2 of this report. In summary, the productive capacity of USACE investments in capital from 1928 through 2016 is reduced by using a hyperbolic decay function, updated to 2016 prices and accumulated to arrive at an estimate of the USACE capital stock. See Figures ES-1 through ES-2 for a graphical representation.

3.1 Investment Data

The OMBIL (Operations and Maintenance Business Information Link) database is used for investment data from 2008 through 2016. OMBIL does not contain the complete historical record of the USACE investments in its capital stock. To the maximum extent possible, OMBIL data were used. Beginning in 1999, data from the USACE OMBIL were used to track spending allocations for MR&T and for Navigation Dredging capital stock investments. Beginning in 2008, data from the USACE OMBIL were used to track spending allocations for Navigation, Flood Risk Management, and Multipurpose capital stock investments. These data were obtained from USACE and entered into the Microsoft Excel workbook consistent with past practices.

Data for earlier capital stock investments were obtained from the USACE Headquarters Programs Division. The Programs Division maintains a database of historical investments in Civil Works projects organized by the functional categories Navigation, Flood Risk Management, Multipurpose, MR&T, and Dredging. These data were provided by USACE in a Microsoft Excel workbook.

The OMBIL database is organized as a cost matrix with seven main funding sources:

1. Baseline[18]
    a. Operations and Maintenance (O&M)
    b. Construction General (CG)
    c. General Investigations (GI)
    d. Management and Operating (M&O)
    e. Mississippi River and Tributaries (MR&T)
2. Regulatory
3. Inland Waterway Trust Fund (IWTF)
4. In Kind Services
5. Power Marketing Agencies (PMAs)
6. Recovery – American Recovery and Reinvestment Act of 2009 (ARRA) funds

[18] Within the Baseline funding category, there are five subcategories where funds are appropriated.

7. Supplemental – Supplemental appropriations

Within each funding source, funds are allocated across 11 official business lines; however, as indicated above, business line specific data are only available from 2008 onward:

1. Navigation (NAV)
2. Flood Risk Management (FRM)
3. Hydropower (HYD)
4. Recreation (REC)
5. Water Supply (WTR)
6. Regulatory
7. Emergency Management
8. Environmental Stewardship (ENS)
9. Aquatic Ecosystem Restoration (AER)
10. Environmental cleanup – Formerly Utilized Site Remedial Action Program (FUSRAP)
11. Environmental – other

Within each business line, funds are then allocated among operations, maintenance, and "unknown" investments. However, due to the nature of OMBIL expenditure data, reliable disaggregation into the 11 business lines was challenging because of an incomplete historical record and a large percentage of unassigned expenditures in the OMBIL database. Therefore, expenditures were grouped into mission areas accordingly for capital stock value analysis under which expenditure data could be reliably assigned:

1. Navigation (NAV)
    a. Dredging evaluated separately
2. Flood Risk Management (FRM)
3. Multipurpose, which encompasses:
    a. Hydropower (HYD)
    b. Water Supply (WTR)
    c. Recreation (REC)
4. Mississippi River and Tributaries (MR&T)

These three main mission areas encompass a large majority of the investments made by USACE. The current study also evaluates MR&T as a separate group of expenditures due to the great importance of the MR&T region and contained infrastructure. MR&T investments were not broken out into contained business lines due to data limitations.

The OMBIL data were used to estimate expenditures for the Navigation, Flood Risk Management, Multipurpose, MR&T, and Dredging functional categories using the following process: the navigation data include all CG data for the navigation business line; the FRM data include all CG data from the FRM business line; the multipurpose data sum all CG data from the hydropower, water supply, and recreation business lines; the MR&T data sum all CG data from the MR&T navigation, FRM, hydropower, water supply, and recreation business lines; and the navigation dredging data include all O&M data for navigation dredging. Figure ES-1 shows the combined annual investments for the Navigation, Flood Risk Management, Multipurpose, MR&T, and Dredging functional categories from 1928 to 2011. These investments include major rehabilitation spending from 1936 through 2016. It should be noted that the 2008 to 2013 increase in USACE capital stock investments shown in Figure ES-1 is largely attributable to funds provided by ARRA.

OMBIL includes a significant "Unknown" component. "Unknown" investments in OMBIL account for approximately 60% of the total annual construction general appropriations from FY 2008 through FY 2016. This high "Unknown" component is due in part to funds provided through ARRA. In keeping with previous analyses, all unknown costs are assumed to be investments in productive capital. In this study, these costs were proportionally allocated across the Navigation, Flood Risk Management, and Multipurpose functional categories, using a 25-year average allocation pattern based on the period 1983 to 2007. Accordingly, the unknown investments in each year between 2008 and 2016 were allocated 35.2% to Navigation, 52.7% to Flood Risk Management, and 12.1% to Multipurpose functional categories.

3.2 Capital Stock Calculations

Following the OECD procedure identified in Section 2.3, the methodology used to perform the PIM calculation is as follows.

1. **Characterize the Capital Stock Inventory:** Characterization of the five Civil Works functional categories (i.e., Navigation, Flood Risk Management, Multipurpose, MR&T, and Dredging) is provided below. In summary, these categories include all the Civil Works projects funded for these categories through USACE Civil Works Program appropriations, representing the entire capital stock inventory built for these five functional categories.

2. **Determine the Assumptions to be Used:** An overview and determination of the assumptions used to define the retirement age and age-efficiency profiles have been described in the Methodology Section. These assumptions are: (1) service life of 60 years for each functional category except for Navigation, which is assumed to have a service life of 75 years, and Dredging, which is assumed to have a service life of 15 years, and (2) use of a hyperbolic function with a β of 0.6 to describe the pattern of asset deterioration (age-efficiency profile) for all functional categories except for Navigation, which uses 0.5, and Dredging, which uses a straight-line deterioration pattern. These assumptions were based on literature reviews, past practices, and experiential knowledge.

3. **Determine the Beginning Date and Beginning Values for the Calculation:** The beginning date is based on the first-year financial data are available. These dates are 1928 for MR&T; 1936 for Navigation, Flood Risk Management, and Multipurpose; and 1963 for the Dredging functional category. Data were not available to determine the extent, age, or value of any pre-existing capital stock portfolios for any of the five functional categories. Therefore, consistent with prior studies, the beginning value is considered zero for the purposes of these calculations.

4. **Calculate the USACE Capital Stock Value:** The last step is to use the data and assumptions described in this report and apply PIM to the time series of investments provided by USACE.

3.2.1 Navigation

Inventory Characterization

USACE maintains approximately 12,000 miles of shallow draft inland and intracoastal waterways, with 239 lock chambers and dams at 193 sites. In addition, USACE manages over 1,000 harbors, with 13,000 miles of deep draft coastal channels. Except for the assets located within the MR&T area, this inventory represents the USACE Navigation functional category and includes both inland and coastal USACE capital stock.

Historical investment in ports, harbors, and inland waterways infrastructure have generated significant benefits to the nation. This infrastructure allows for the relatively low-cost transportation of a wide range of commodities and goods. More than 2 billion tons of commercial cargo move on 25,000 miles of USACE inland and coastal channels annually (USACE 2016a). In addition, waterborne transportation has been shown to be more fuel efficient compared to other modes of transportation, including rail and truck, thereby reducing the demand for foreign oil and generating less emissions to the atmosphere.

Service Life and Hyperbolic Function Parameters

The capital stock value estimates presented are based upon a 75-year service life and a hyperbolic beta function of 0.5. See Figure 1 above for a graphical representation of hyperbolic functions with different beta values. Descriptive statistics of existing Navigation projects' age discussed earlier in the report showed that the mean age for lock chambers was 64 years, indicating that a large portion of existing navigation assets have long service lives. Thus, it was determined that a service life assumption of 75 years was more appropriate for the Navigation functional category as opposed to the 60-year assumption applied to all other functional categories except Dredging.

Furthermore, the beta function of 0.5 represents a more rapid rate of asset deterioration compared to the 0.6 beta value applied to all other functional categories except Dredging. A beta function of 0.5 is at the low end of the BEA's recommended range of 0.5 to 0.75, which implies a faster rate of deterioration. This lower beta function was chosen for navigation to simulate the added external contribution to asset deterioration caused by sedimentation that navigation projects experience. While sedimentation may play some role in deterioration in other mission areas (e.g., sediment build-up behind a dam), the resulting impacts are generally smaller, occurring at a lower rate than in navigation assets. Therefore, within the current study, it was assumed that navigation assets are impacted by both internal (i.e., regular wear and tear of components) and external (i.e., sedimentation) deterioration, whereas all other mission areas (excluding dredging) are most impacted by internal deterioration.

Capital Stock Calculation

The Navigation capital stock calculation is performed in the accompanying Microsoft Excel workbook. Figures 5 and 6 respectively show the annual investments and the computed capital stock value for this functional category since 1936. While dredging was evaluated separately due to its unique deterioration behavior, it was included in the total Navigation (with dredging) capital stock value estimates since dredging extends the life of Navigation projects. The current total Navigation (with dredging) capital stock is about $73 billion, while Navigation, independent of dredging, is $64.9 billion. Note that dredging records only go back through 1963 while navigation records extend back 30 years earlier to 1936. Therefore, we can only infer the value dredging provided to Navigation projects since 1963.

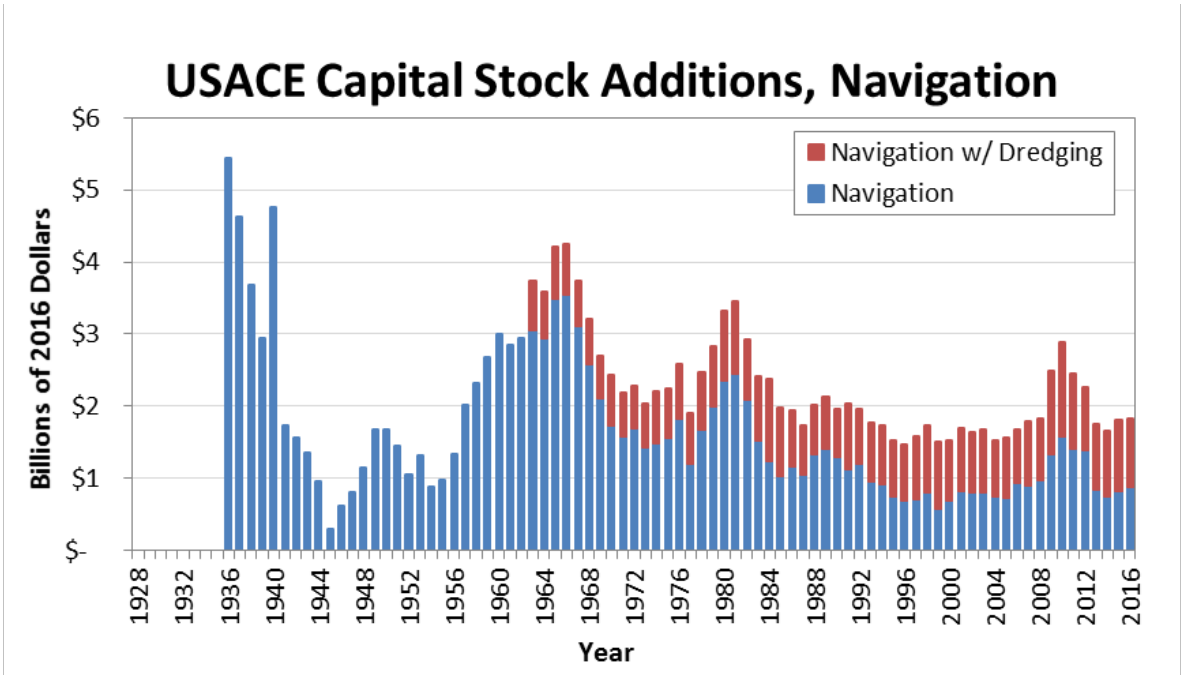

Figure 5
USACE annual investments for the Navigation (with and without Dredging) Functional Category in Billions of 2016 Dollars

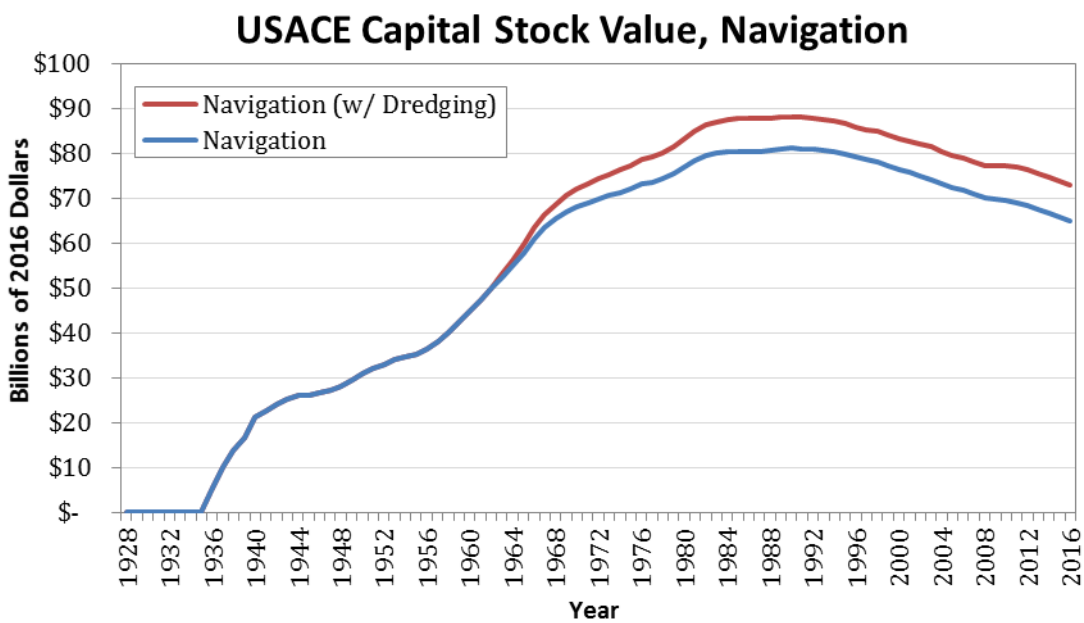

Figure 6
USACE Capital Stock Estimates for the Navigation (with and without Dredging) Functional Category in Billions of 2016 Dollars

Simple observations on the calculated capital stock value covered under the Navigation functional category are as follows:

- Significant investment in the Navigation functional category occurred from 1936 up until WWII (see Figure 5). During WWII, annual investments declined significantly for several years. Following

WWII, annual investments in this stock generally increased each year through about 1966, when it peaked at slightly over $4.3 billion per year (with dredging) and $3.5 billion per year without dredging.

- Annual investment in the Navigation functional category generally declined after 1966 until about 1984. However, because investment continued to exceed estimated deterioration during this period, the capital stock continued to increase through 1984. Since 1984, investment in the total navigation (with dredging) stock has hovered around $2 billion per year (all values in 2016 dollars), or about $1 billion per year for navigation excluding dredging.
- The value of the total Navigation (with dredging) capital stock peaked in 1991 at about $88 billion. Similarly, Navigation, independent of dredging, peaked in1993 at about $80.7 billion. Since 1993, annual deterioration in the estimated capital stock has exceeded investments, resulting in a decreasing capital stock.
- The 2016 USACE total Navigation (with dredging) capital stock value is $73 billion, or approximately what is was in 1971. Similarly, the 2016 USACE Navigation capital stock value, excluding dredging is $64.9 billion, or about what it was between 1967 and 1968.
- The total Navigation (with dredging) capital stock has declined a little over 25% since peaking in 1991 and is currently about 83% of its peak 1991 value.

3.2.5 Dredging

At present, there is a portion of costs associated with navigation dredging that is categorized as maintenance. This study employs data on the expenditures for maintenance dredging for navigation projects to derive a capital stock estimate for investments in navigation maintenance dredging.

As mentioned earlier in this report, the Dredging functional category capital stock value is derived using a different set of assumptions from those that are used for the other four USACE functional categories. In Section 2, the methodology used to estimate the Dredging functional category capital stock value is discussed. This section presents a brief description of dredging infrastructure and investment as well as the capital stock estimate for the dredging functional category. This section also reviews the impact of dredging maintenance-related improvements on the USACE productive capital stock.[19]

Inventory Characterization

USACE dredging projects exist throughout the country. Dredging of inland and coastal waterways under the USACE purview involves the removal of accumulated sediment that, over time, decreases channel depth and availability. Removing this sediment allows for improved passage of larger vessels with deeper draft, thus, benefiting waterborne commerce using the dredged channel or harbor.

Capital Stock Calculation

Figures 7 and 8 how the annual investment in dredging maintenance and the estimated Dredging capital stock value from 1963 through 2016, respectively. Figure 7 shows that investment in dredging maintenance has remained relatively stable over time, remaining largely within the band of $600 to $800 million annually. However, spending does appear to be trending upward over time and spiked in the period 2009 through 2011. This sudden increase follows a trend observed in the investment data for the other functional categories, related to spending from ARRA.

[19] Maintenance dredging-related investments primarily refer to sustaining deep and shallow-draft navigation channels and other navigation-related infrastructure such as turning basins and harbors.

Simple observations of the calculated capital stock value covered under the Dredging functional category are as follows:

- Dredging capital stock value grew at a relatively steady pace until about 1985, increasing at an average rate of 11.8% annually. It remained stable until 2009, at which point it began growing again as funding for maintenance dredging from the Harbor Maintenance Trust Fund increased.
- The 2016 Dredging capital stock value of $8.1 billion represents the maximum (i.e., peak) dredging capital stock estimate.

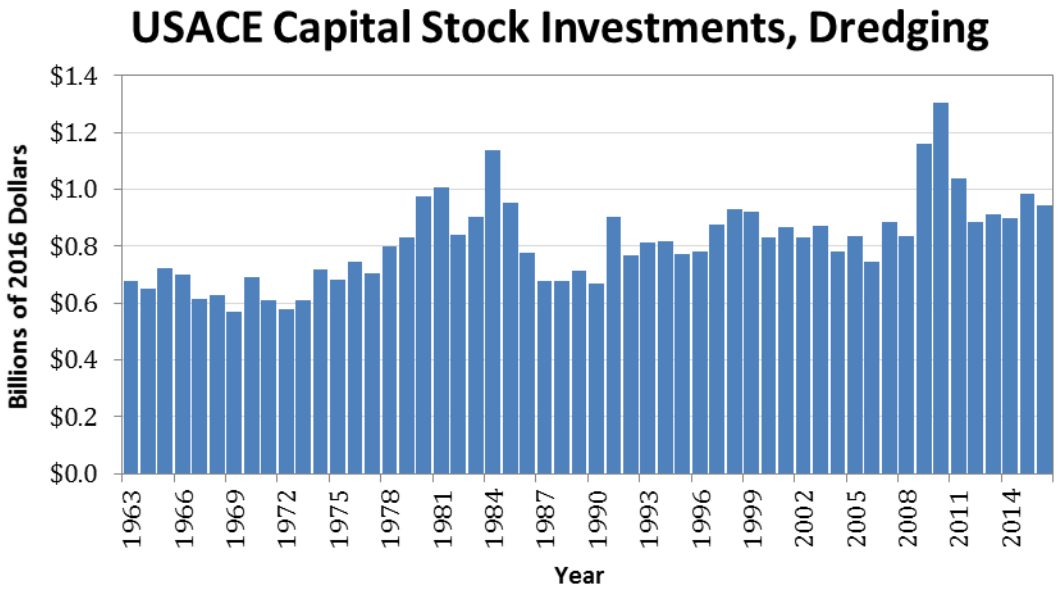

Figure 7
USACE Historical Dredging Investment, 1963 to 2016

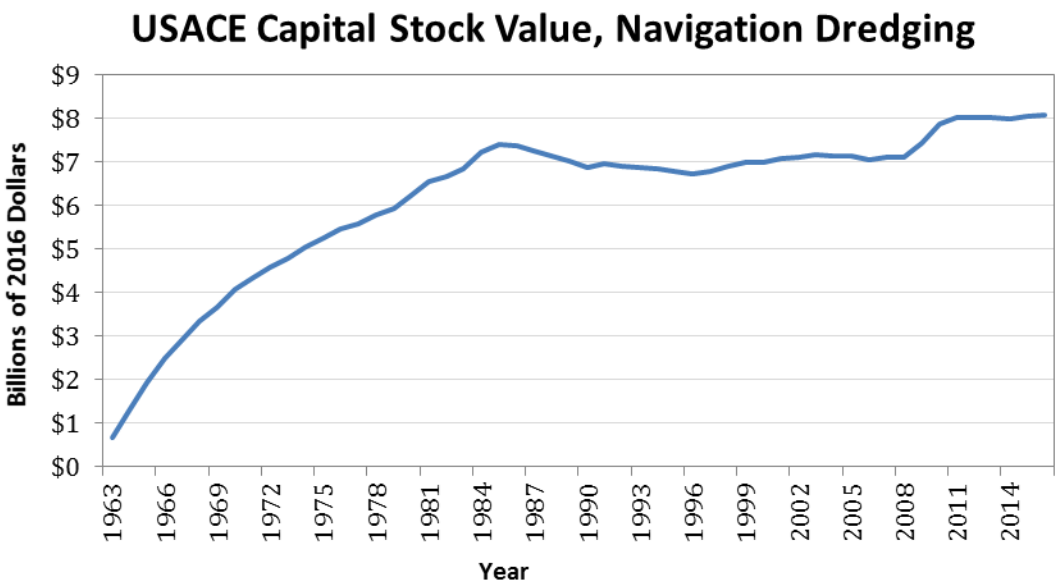

Figure 8
USACE Capital Stock, 1963 to 2016 – Dredging

3.2.2 Flood Risk Management

Inventory Characterization

USACE owns and operates 715 dams located throughout the U.S. In addition, USACE built or controls 14,700 miles of levees (U.S. Congress, Senate 2015). This infrastructure provides significant benefits to the nation. It is estimated that for every dollar invested in USACE dams and levees between 1928 and 2010, America saved $7.17 in flood-related damages (U.S. Congress, House 2012).

Capital Stock Calculation

The calculation pertaining to the Flood Risk Management functional category is performed in the accompanying Microsoft Excel workbook. Figures 9 and 10 respectively show the annual investments and the calculated capital stock for Flood Risk Management for 1936 through 2016.

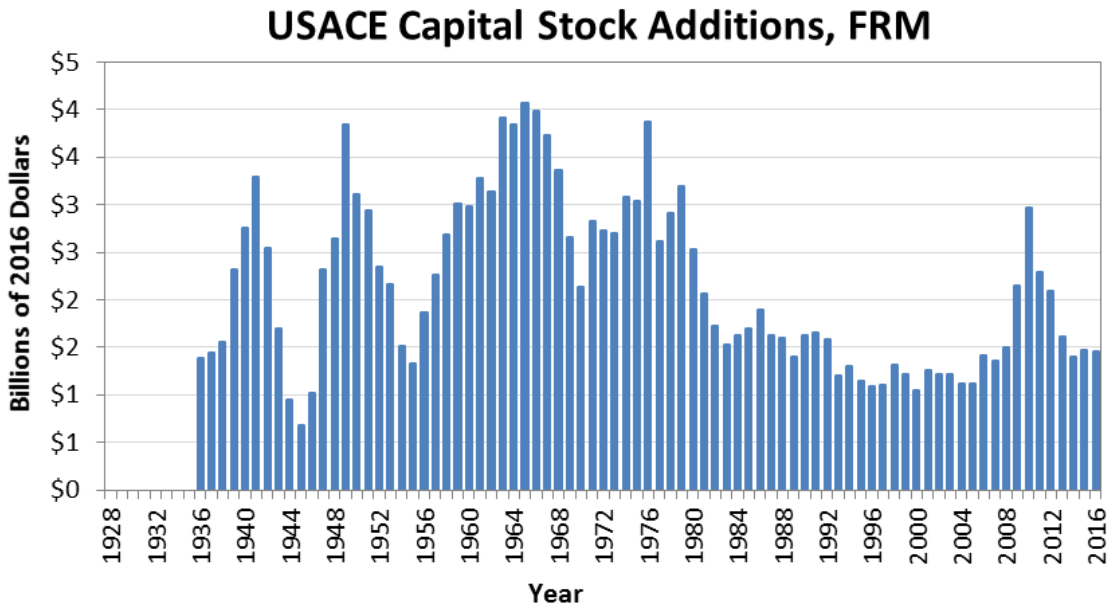

Figure 9
USACE Historical Flood Risk Management Investment, 1936 to 2016

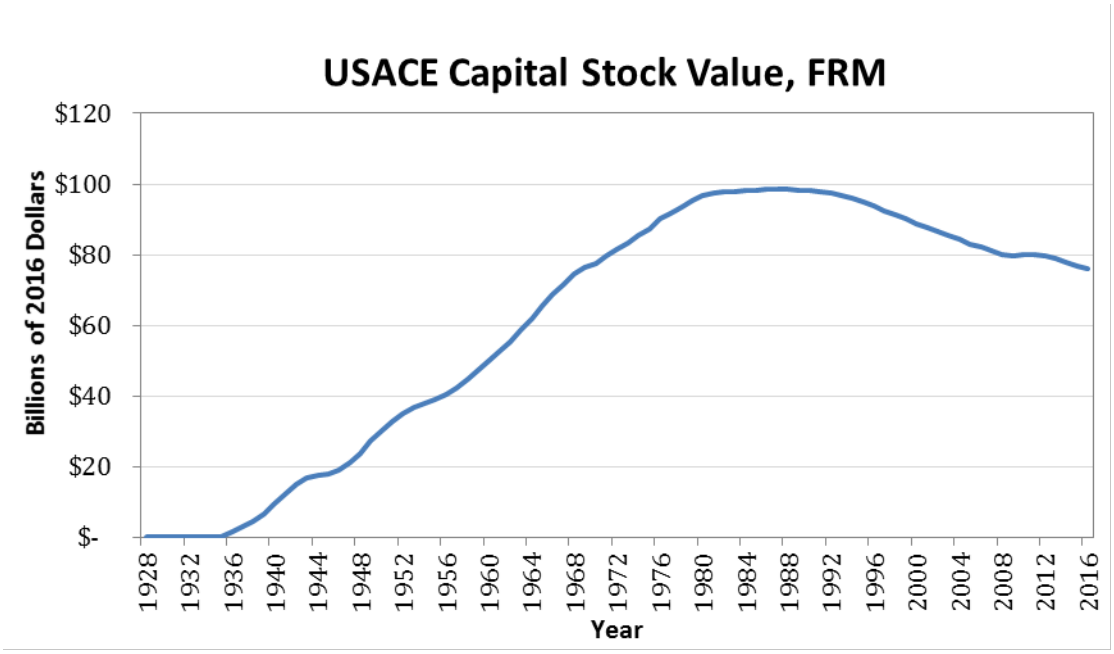

Figure 10
USACE Capital Stock Estimates for the Flood Risk Management Functional Category in Billions of 2016 Dollars

Simple observations of the calculated capital stock value covered under the Flood Risk Management functional category are as follows:

- The rate of investments (in 2016 dollars) made in this stock starting in 1936 remained relatively consistent through 1987, increasing at an average rate of 0.57% per year.
- The USACE Flood Risk Management capital stock value peaked in 1987 at $98.6 billion. It then declined at a generally steady rate of 0.90% each year until 2016. Since 1987, annual deterioration in the estimated capital stock has exceeded investments.
- The 2016 USACE Flood Risk Management capital stock value is $75.9 billion, or approximately what it was between 1968 and 1969 and about 77% of its peak 1987 value.

3.2.3 Multipurpose Inventory Characterization

The Multipurpose functional category covers a variety of USACE assets that fulfill multiple authorized purposes that may include flood risk management, water supply, hydropower generation, navigation, recreation, and environmental restoration. USACE hydropower infrastructure falls under the Multipurpose functional category; therefore, for the purposes of this study, all hydropower facilities are accounted for under the Multipurpose functional category.

Capital Stock Calculation

The calculation pertaining to the Multipurpose functional category is performed in the accompanying Microsoft Excel workbook. Figures 11 and 12 respectively show the annual investments and the calculated capital stock for Multipurpose for 1936 through 2016.

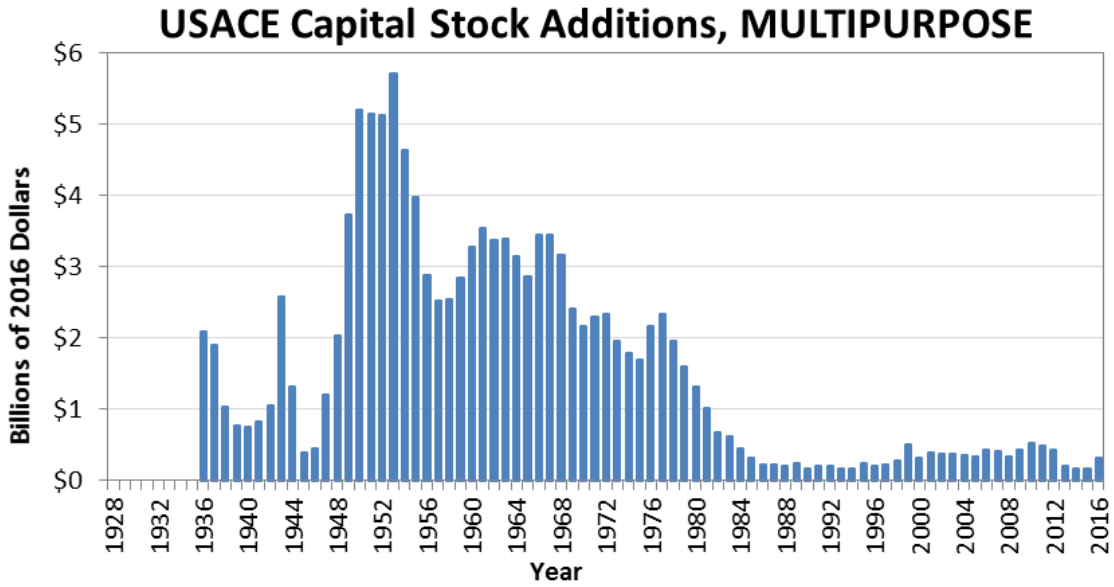

Figure 11
USACE Historical Multipurpose Investment, 1936 to 2016

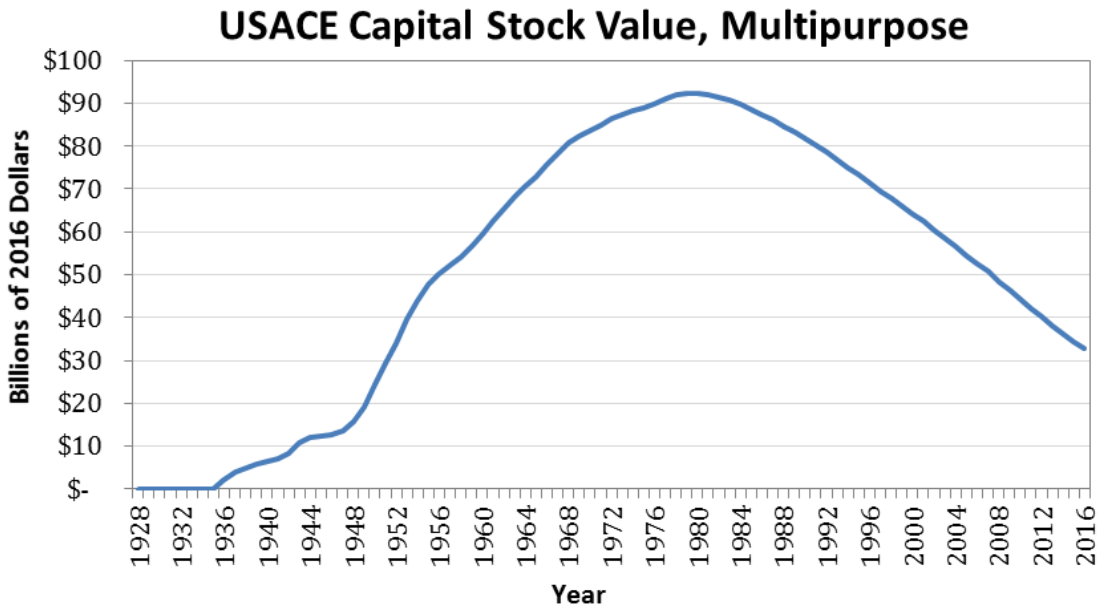

Figure 12
USACE Capital Stock Estimates for the Multipurpose Functional Cateogry in Billions of 2016 Dollars

Simple observations on the calculated capital stock value covered under the Multipurpose functional category are as follows:

- The rate of investments made in this stock, starting in 1936, exhibited a steady growth through the mid-1950s, increasing at an average rate of 5.9% annually from 1936 through 1953. Annual

investment peaked in 1953 at $5.7 billion (in 2016 dollars). Since 1953, annual investments in 2016 dollars have declined at an average rate of 3.1% annually (see Figure 11).

- The peak USACE Multipurpose capital stock value of $92.4 billion occurred in 1980. Since 1980, annual deterioration in the estimated capital stock has exceeded investments.
- The average rate of decline from 1980 to 2016 was 2.4% annually.
- The 2016 USACE Multipurpose capital stock value is $32.6 billion, or approximately what it was between 1951 and 1952 and about 35% of its peak 1980 value.
- By 1986, most large multipurpose projects had already been built, were in the process of being built, or had already been rejected on economic or environmental grounds. Additionally, projects that might have been approved in the past would now be rejected because of cost-sharing requirements, budgetary pressures, or environmental impacts.

3.2.4 MR&T

Inventory Characterization

The MR&T functional category consists of a variety of infrastructure types, including levees, navigation works, and dams. This functional category is unique in several ways. It is the only functional category whose infrastructure is defined by geography rather than a function or purpose. The MR&T functional category includes 3,727 miles of levees and floodwalls providing flood risk reduction to approximately 4 million people in the Lower Mississippi River Basin (USACE 2009). This levee system is enhanced by more than 1,000 miles of revetment infrastructure that protects the system from erosion.[20] Other MR&T assets include navigation infrastructure such as locks, dams, and dikes. In 2011, MR&T infrastructure prevented an estimated $110 billion in damages to the people and property protected by the MR&T system (Mississippi River Commission 2011).

Capital Stock Calculation

The calculation pertaining to the MR&T functional category is performed in the accompanying Microsoft Excel workbook. Figures 13 and 14 respectively show the annual investments and the calculated capital stock for the MR&T functional category for 1928 through 2016.

[20] A revetment is a structure characterized by small concrete blocks joined together by wires placed on the river bank to maintain the proper channel alignment and protect nearby levees from bank erosion (USACE 2009).

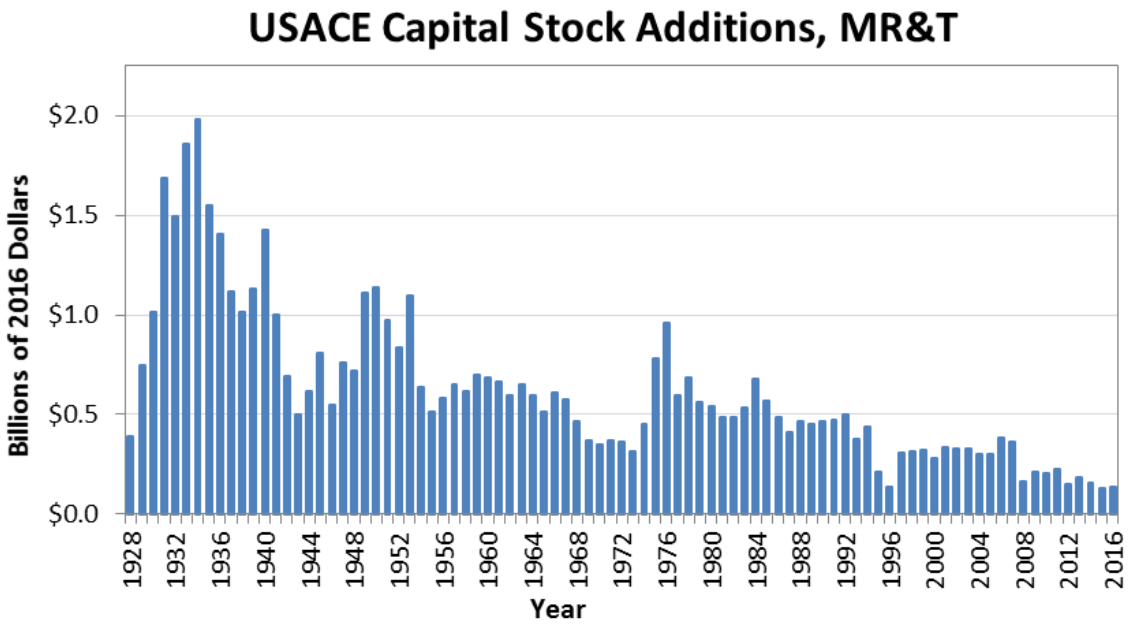

Figure 13
USACE Historical MR&T Investment, 1928 to 2016

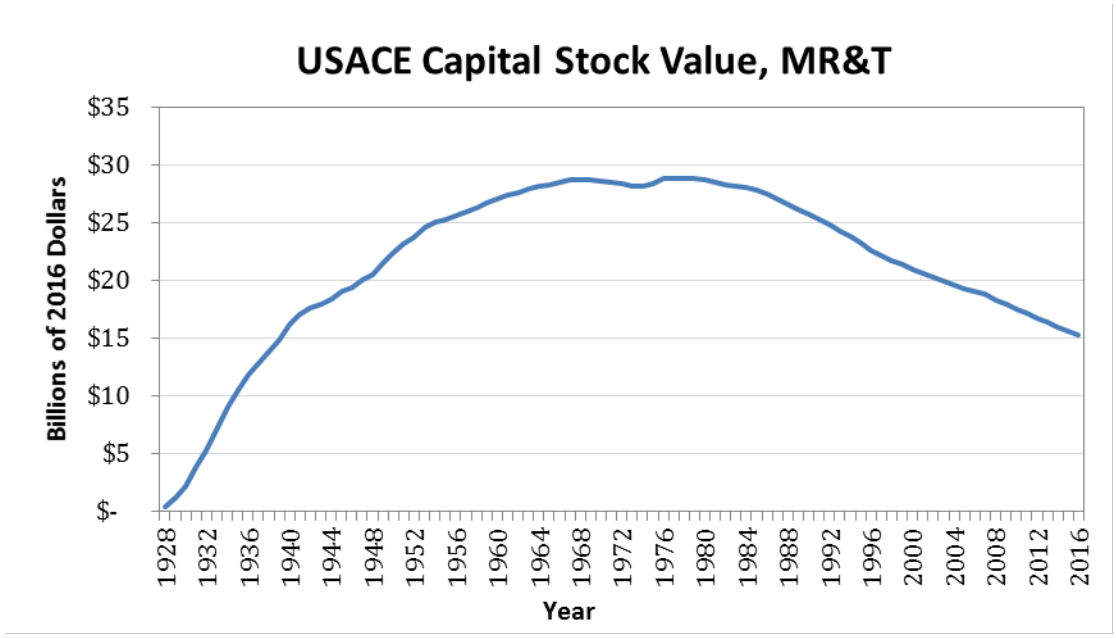

Figure 14
USACE Capital Stock Estimates for the MR&T Functional Category in Billions of 2016 Dollars

Simple observations on the calculated capital stock value covered under the MR&T functional category are as follows:

- The greatest investment in this stock occurred from 1928 through 1940 (see Figure 13); investments increased at an average annual rate of 11.4% during this period. Since then, annual

investments in 2016 dollars have been variable, ranging from a high of $1.134 billion in 1950 to a low of $128 million in 2015 and averaging $621 million annually.

- The peak USACE MR&T capital stock value occurred in 1978 at $28.9 billion. Since 1978, annual deterioration in the estimated capital stock has exceeded investments.
- The average rate of decline from 1978 to 2016 is 1.3% annually.
- The 2016 USACE MR&T capital stock value is $15.2 billion, or approximately what it was between 1939 and 1940 and about 53% of its peak 1978 value.

3.3 USACE Capital Stock Calculation

The measure of capital stock value for the entire USACE inventory is obtained by adding the value for each functional category in each year. Figures 15 and 16 below present the historical annual investments and the aggregated USACE capital stock value.

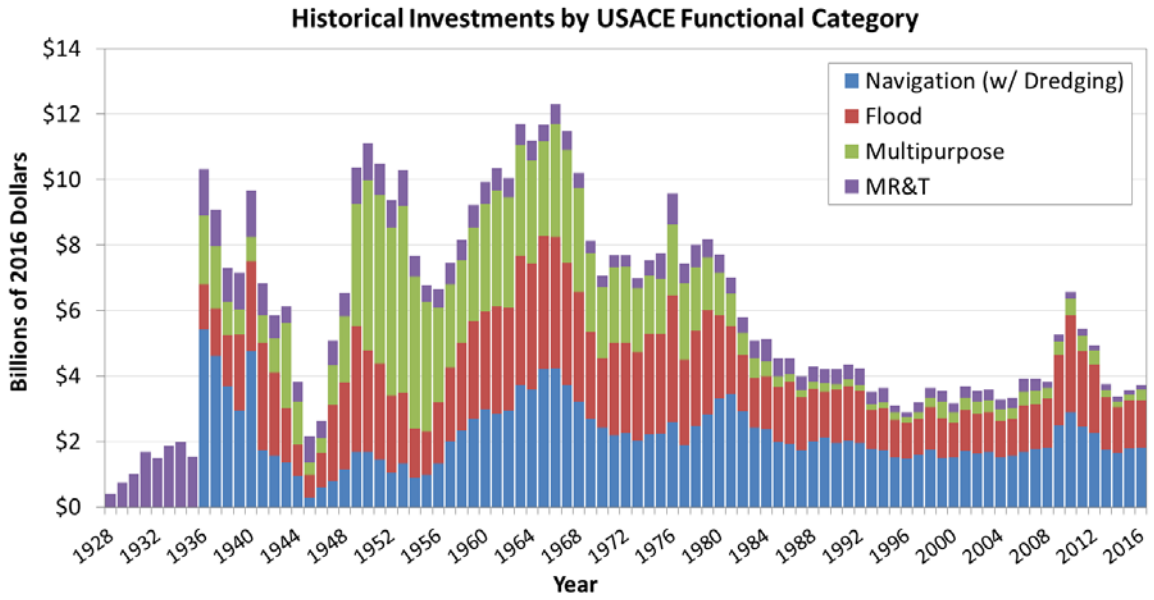

Figure 15
USACE Historical Investments by functional category, 1928 to 2016 in Billions of 2016 Dollars

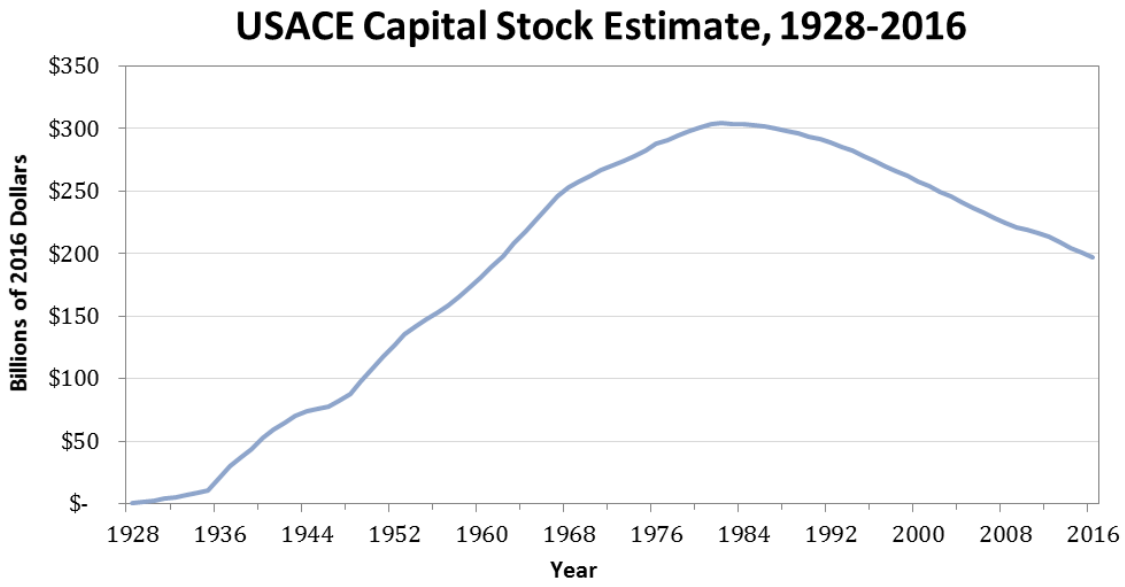

Figure 16
USACE Capital Stock Estimates, 1928 to 2016 in Billions of 2016 Dollars

Simple observations of the calculated total USACE capital stock value are as follows:

- As shown in Figure 15, annual investment in USACE capital stock, in 2016 dollars, peaked in 1966 at $12.3 billion. Since 1966, investments have decreased, on average, at a rate of about 2.36% annually. Total capital stock investments in 2016 were $3.7 billion. These investments include CG account appropriations, allocated Unknown account appropriations, MR&T construction expenditures, and Dredging expenditures.
- The USACE capital stock value peaked in 1982 at $303.9 billion. It then declined at about an average annual rate of 1.38% through 2016. Since 1982, annual deterioration in the estimated capital stock has exceeded investments.
- The 2016 USACE capital stock value is $196.8 billion, or approximately what it was in 1961.

Dredging Impact on Total Capital Stock Estimates

Dredging-related capital stock has been growing since 1963, as noted above in Section 3.2.5. It has also been growing steadily on an annual basis as a percentage of total USACE water resources capital stock expenditures. Figure 17 shows that in 2016, the Dredging functional category accounted for 25% of the total USACE Civil Works water resources capital stock.

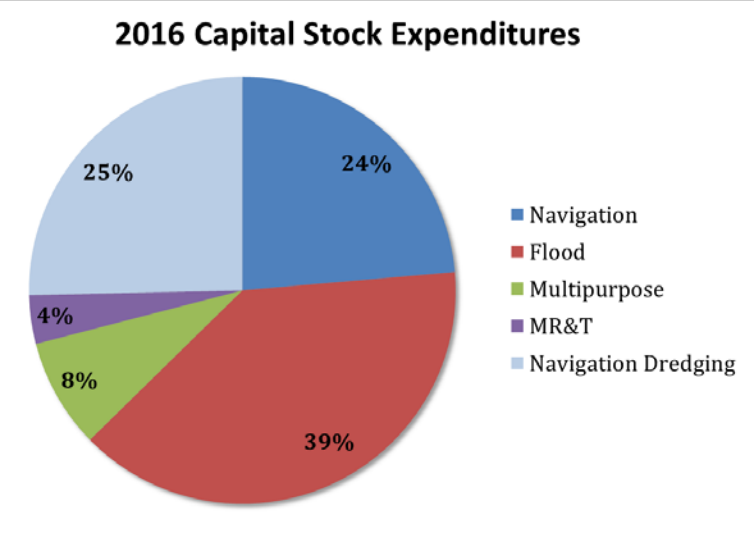

Figure 17
USACE Civil Works FY 2016 Capital Stock Expenditures

Even though dredging maintenance costs have become an increasingly more significant portion of capital stock expenditures due to their shorter service life and faster rate of deterioration, dredging still represents only a small portion of the total productive capital stock as shown in Figure 18. At present, dredging accounts for less than 4% of the 2016 USACE capital stock value. Given this small percentage, and despite the growth in dredging maintenance expenditures over time, the overall USACE capital stock value is not materially impacted by this growth in spending on maintenance dredging. However, halting the spending on dredging would result in the shoaling of navigation channels, decreasing the productive capacity of the USACE navigation capital stock.

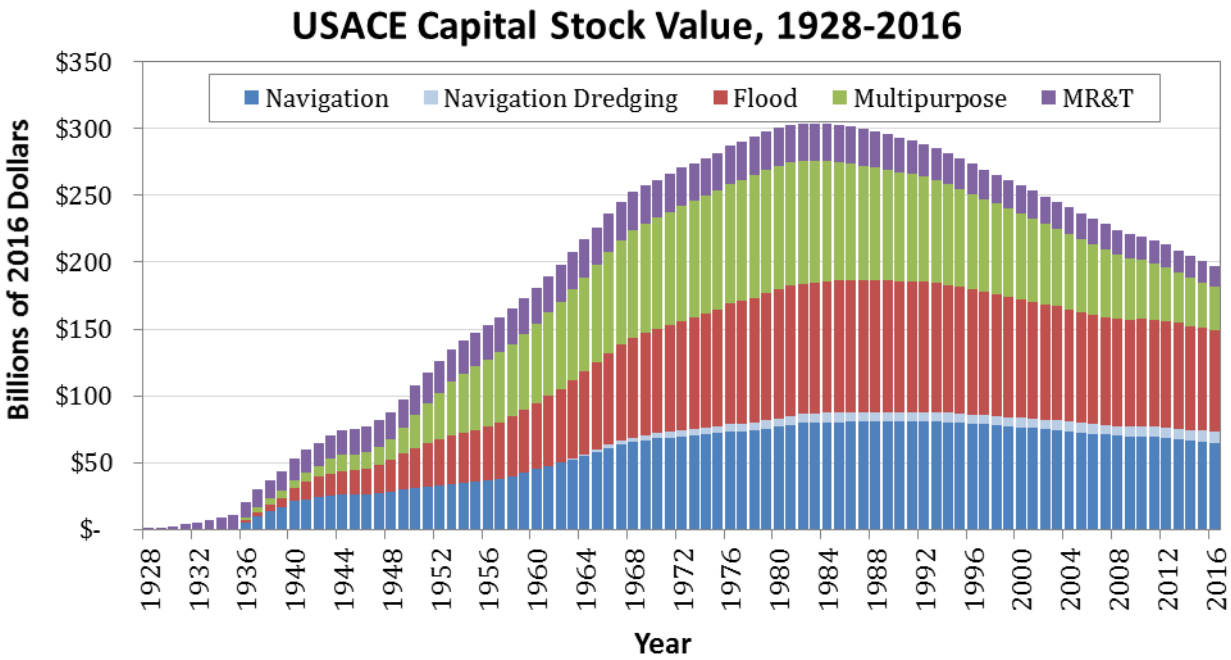

Figure 18
USACE Capital Stock Value Disaggregated by Functional Category

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Section 4
Sensitivity Analysis

This section presents a discussion of the sensitivity analysis of key assumptions used in the USACE capital stock calculation.

4.1 Overview

We cannot truly know the value of the USACE capital stock. However, we can estimate it using established techniques, available data, and reasonable assumptions and judgments. These factors introduce significant uncertainty into our estimates. Sensitivity analysis is used in this report to better understand the impact of uncertainty surrounding different model parameters and identify those parameters that most significantly impact the resulting capital stock value estimates.

The 2013 study used a Monte Carlo analysis to address uncertainty concerns. However, this analysis was criticized by the external review panel due to a lack of information on the probability distributions of the input parameters to the PIM model. Therefore, the current report employs sensitivity analyses to evaluate the response of the capital stock value estimates to variations in the age-efficiency profile, the service life value, and the hyperbolic function rate of decline constant. The resulting range of capital stock estimates generated is presented to illustrate the model's sensitivity to the variability of each of the inputs. Note that all Navigation values presented in Section 4 do not include dredging, which is included as a separate category for analysis. This distinction is made to illustrate the unique behavior of the dredging functional category.

4.2 Age-Efficiency Profile Sensitivity Analysis

The PIM model takes as input historic investments in capital stock. The age-efficiency profile describes the pattern of productive capacity decay of those investments as they age and is a critical assumption in calculating the capital stock value. Research on the subject supports the use of a hyperbolic age-efficiency profile in estimating capital stock values and is, therefore, used in this study (OECD 2009). Additionally, as mentioned previously, the hyperbolic age-efficiency profile was used based on the assumption that Civil Works infrastructure will have high productive capacity (low deterioration) for a long period of time after it is placed in operation and experience a greater loss in productive capacity (more deterioration) as the infrastructure ages. The hyperbolic age-efficiency profile was found to best simulate this pattern of deterioration. To understand the impacts of using other age-efficiency profiles, sensitivity analyses were performed on the PIM spreadsheet model using One Hoss-Shay, straight-line, and geometric functions (see Figure 18).

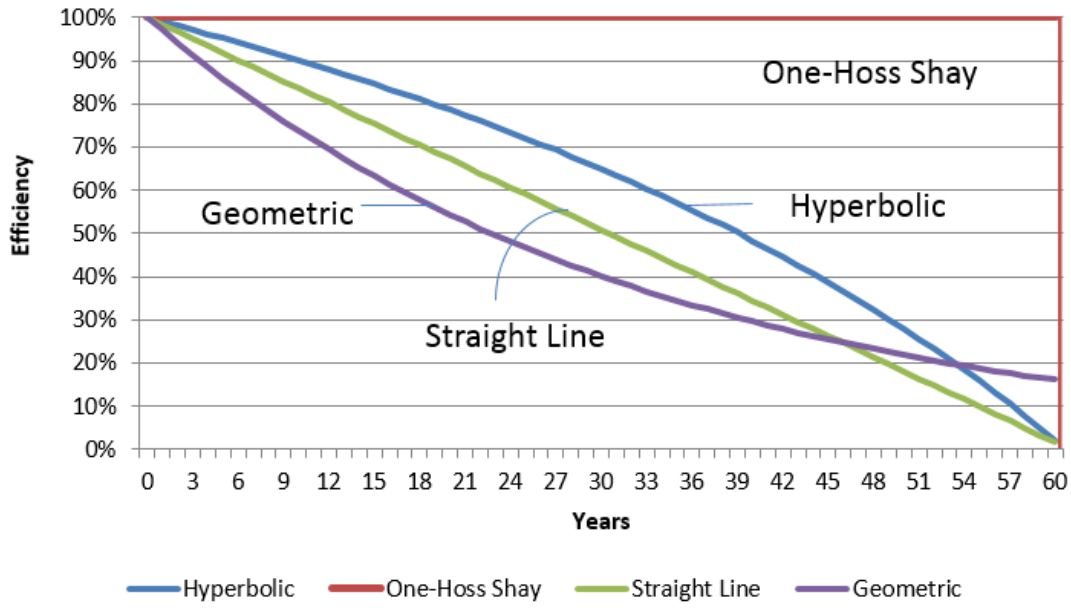

Figure 19
Age-Efficiency Profile Comparison

The capital stock estimates derived using different age-efficiency profile was compared to the hyperbolic function used in this study (baseline). The results are shown in Table 3 and Table 4. Table 3 shows capital stock values by business line for the different age-efficiency profiles, and Table 4 shows the percent change from the baseline.

Table 3: Age-Efficiency Profile Sensitivity Analysis (Billions 2016 $)

Efficiency Profile	Navigation (w/o dredging)	FRM	MP	MR&T	Navigation Dredging	Total
Baseline	$64.9	$75.9	$32.6	$15.3	$8.09	$197
One-Hoss Shay	$113	$132	$76.7	$26.5	$14.8	$362
Straight Line	$50.7	$55.8	$20.9	$11.0	$8.09	$146
Geometric	$38.0	$52.4	$22.0	$10.1	$12.0	$135

Table 4: Age-Efficiency Profile Sensitivity Analysis (% change from Baseline)

Efficiency Profile	Navigation (w/o dredging)	FRM	MP	MR&T	Navigation Dredging	Total
One-Hoss Shay	73.3%	73.3%	135%	73.9%	82.4%	83.9%
Straight Line	-21.9%	-26.6%	-36.1%	-27.9%	0.00%	-25.6%
Geometric	-41.5%	-30.9%	-32.5%	-33.7%	47.8%	-31.7%

As might be expected, switching to a One-Hoss Shay age-efficiency profile increases the value of the capital stock, whereas switching to a straight line or geometric age-efficiency profile decreases the value of the capital stock. The value for the current (i.e., 2016) capital stock varies from $362 billion when using a One-Hoss Shay retirement profile, to $135 billion when using a geometric profile. This output indicates a range of $227 billion in the potential outcomes for 2016. However, the results for the One-Hoss Shay profile are

unusual compared to the other three outcomes, which have a relatively small range of $62.3 billion separating them.

The results are intuitive based on the age-efficiency profiles (Figure 18) in that the value of the 2016 USACE capital stock is a function of the deterioration patterns of the particular age-efficiency profiles. In the case of a One-Hoss Shay, the capital stock valuation is significantly higher than estimates using other functions because, under this age-efficiency profile and assuming 60- and 75-year service lives, USACE has not yet begun experiencing significant deterioration in many of its past capital stock investments. It is possible that the One-Hoss Shay is representative of some USACE assets given that USACE infrastructure continues to provide steady and even increasing benefits despite its increasing age. Using a shorter service life assumption would alter the results to be more in line with the other alternatives. For example, using a service life of 50 years would reduce the One-Hoss Shay capital stock estimate to $244 billion.

The geometric age-efficiency profile assumes higher deterioration in the capital stock in early years and lower in later years. As noted in Section 2, the One-Hoss Shay and straight-line age-efficiency profiles are hyperbolic age-efficiency profiles assuming endpoint βs (i.e., β of zero for the straight-line age-efficiency profile and a β of 1.0 for the One-Hoss Shay age-efficiency profile).

4.3 Service Life Sensitivity Analysis

Capital stock value estimates are most sensitive to service life assumptions, making service life the most important parameter defined in the PIM method. The service life describes the expected useful life of an investment and is a critical assumption in calculating the capital stock value. Based on a review of the age profile of the existing USACE capital stock, the current study assumes a 60-year service life for the Flood Risk Management, Multipurpose, and MR&T functional categories; a 75-year service life for the Navigation functional category; and a 15-year service life for navigation dredging. To understand how service life-assumptions impact the PIM estimate of the USACE capital stock, it is instructive to investigate alternative assumptions with respect to the service lives of the investments that comprise the PIM estimate of the USACE capital stock.

Table 5 shows the statistics related to the age of USACE multipurpose and FRM dams, and navigation lock chambers and dams. About 35% of these dam structures are deemed to be in "poor" or "unsatisfactory" condition. USACE navigation structures (median age of 60 years), are slightly older than USACE dams (median age of 55 years). The variation in age is fairly high within both structure types with respective standard deviations of 20 years for dam structures and 28 years for navigation locks and dams. These high standard deviations are, in part, due to the different eras of USACE infrastructure investment. The maximum age for both navigation and dam structures is around 180 years, which suggests that, in very special cases, both dam and lock chamber structures can long exceed their expected service life. While these 180-year old projects are anomalies in the USACE portfolio, about 19% of USACE multipurpose and FRM dams are between 70 and 90 years old and about 22% of navigation structures are currently between 80 and 100 years old. In other words, more than 20% of USACE structures have already exceeded their respective estimated service lives of 60 and 75 years. See Figures 20 and 21 for histograms of the current age distributions of these two types of structures. Note that these age distributions do not take into account any major rehabilitations or structure replacement. Therefore, the statistics presented in this Section are only used as a rough guide for

Table 5: Age Distribution Statistics for both USACE Dams and Navigation Structures (Snorteland 2017; Riley 2017)

Statistic	USACE Dams	USACE NAV Structures
Mean Age	58	65
Median Age	55	60
Minimum Age	6	8
Maximum Age	178	181
Standard Deviation	20	28

estimating upper bounds of structure service life for sensitivity analysis purposes.

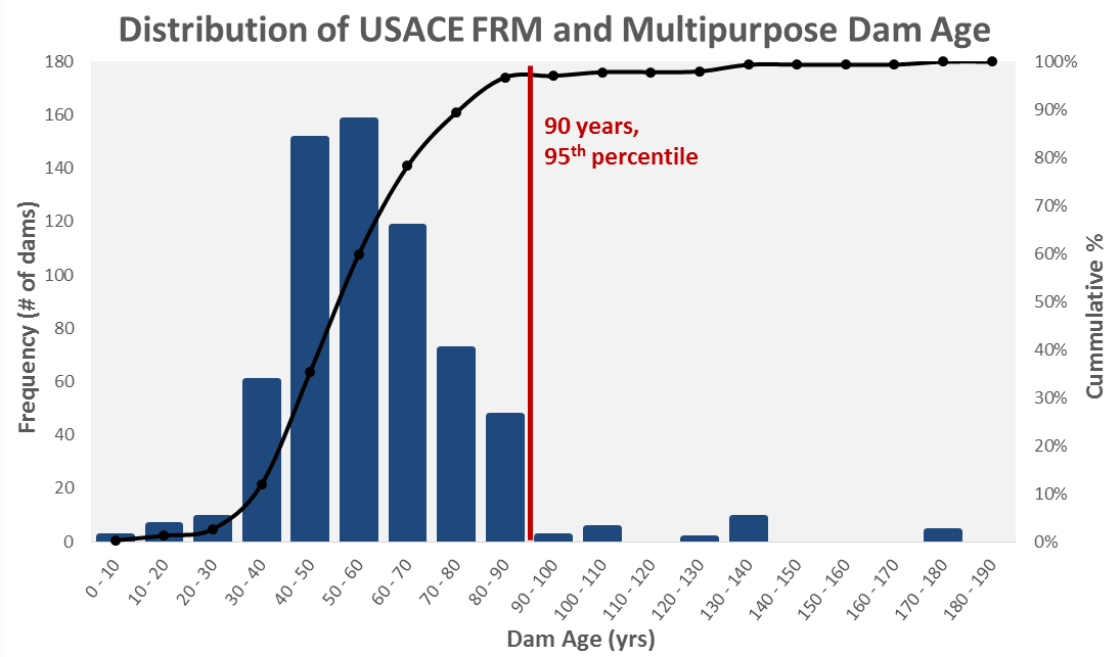

Figure 20 USACE Dam Age Distribution
Current age distribution across all USACE dams with a mean of 58, median of 55, and standard deviation of 20 years. Age is positively skewed, showing that over half of the dams are currently over 50 years old (derived from data provided by Nate Snorteland, IWR-RMC).

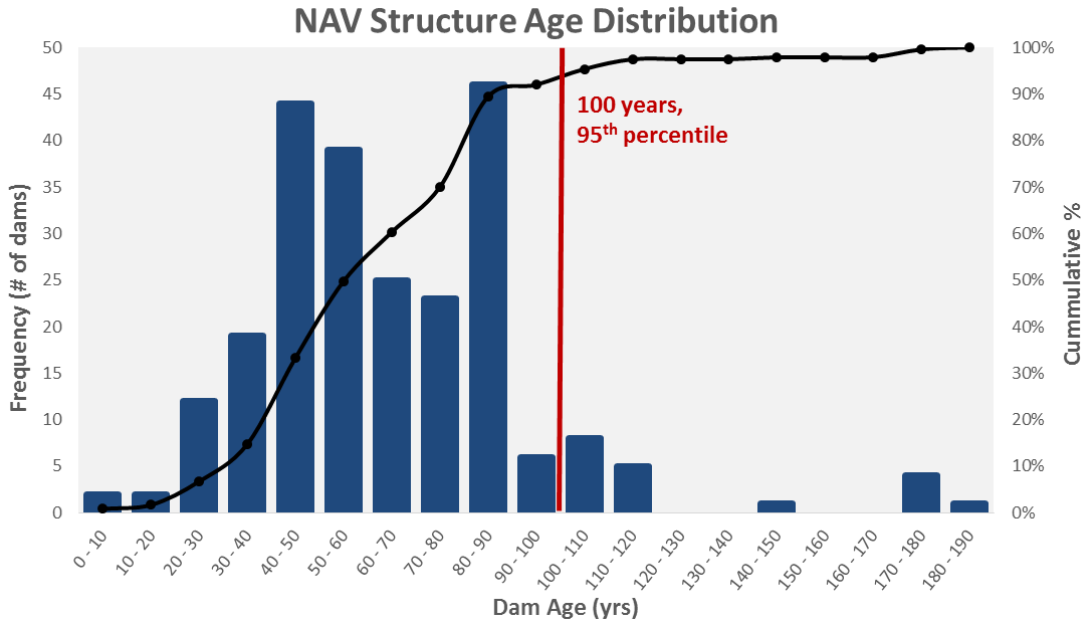

Figure 21 USACE Navigation Lock Chamber Age Distribution
Current age distribution across all USACE Navigation lock chambers with mean, median, and standard deviation values respectively of 65, 60 and 28 years (derived from data provided by Steven Riley, IWR). The bimodal distribution shows a high proportion of lock chambers are either around 40-60 or 80-90 years old, which reflect the two peaks in navigation infrastructure seen in the 1930s and mid-1960s.

A sensitivity analysis was used to evaluate the impact of different service life assumptions on the resulting 2016 Capital Stock value. Based on the USACE infrastructure current age distributions (Figures 20 and 21), upper bounds of 90 years for dams (assumed to encompass FRM, MP, and MR&T) and 100 years for navigation infrastructure were chosen. These upper bounds were chosen because they represent the respective 95th percentile ages for existing Corps dams, and navigation structures. A lower bound of 50 years for all functional categories except for dredging based as based on previous Capital Stock Report service life assumptions. Because data were not available related to dredging project service lives, upper and lower bounds of +/- 10% were evaluated for the dredging functional category to evaluate dredging capital stock sensitivity to service life estimates.

The sensitivity analysis results are shown in Table 6 through Table 9 where Tables 6 through 8 respectively show sensitivity analysis results for Navigation; Dredging; and Flood, Multipurpose, and MR&T functional categories. A summary of service life sensitivity is presented in Table 9, which reports a final range of total Capital Stock values of $131 to 325 billion (in 2016 $).

Table 6: Service Life Sensitivity Analysis for Navigation excluding dredging (Billions 2016 $ and % change from baseline)

Efficiency Profile	Baseline (75 yr)	Lower Bound (50 yr)	Upper Bound (100 yr)
Billions 2016 $	$64.9	$35.6	$89.0
% change from Baseline	---	-45.1%	37.0%

Table 7: Service Life Sensitivity Analysis for Navigation Dredging (Billions 2016 $ and % change from baseline)

Efficiency Profile	Baseline (15 yr)	Lower Bound (-10%)	Upper Bound (+10%)
Billions 2016 $	$8.09	$7.43	$8.76
% change from Baseline	---	-8.16%	8.27%

Table 8: Service Life Sensitivity Analysis for Flood Risk Management, Multipurpose, and MR&T functional categories (Billions 2016 $ and % change from baseline)

Efficiency Profile	Units	Baseline (60 yr)	Lower Bound (50 yr)	Upper Bound (90 yr)
FRM	Billions 2016 $	$75.9	$57.6	$120.0
	% change from Baseline	---	-24.1%	58.3%
Multipurpose	Billions 2016 $	$32.6	$18.7	$77.5
	% change from Baseline	---	-42.7%	137%
MR&T	Billions 2016 $	$15.2	$11.8	$29.7
	% change from Baseline	---	-22.4%	95.0%

Table 9: Summary of Service Life Sensitivity Analysis (Billions 2016 $)

Efficiency Profile (Baseline Service Life)	Navigation (w/o dredging) (75 yr)	FRM (60 yr)	MP (60 yr)	MR&T (60 yr)	Navigation Dredging (15 yr)	Total ---
BILLIONS 2016 $						
Baseline	$64.9	$75.9	$32.6	$15.2	$8.09	$197
Lower Bound	$35.6	$57.6	$18.7	$11.8	$7.43	$131
Upper Bound	$89.0	$120	$77.5	$29.7	$8.76	$325
% Change from Baseline						
Baseline	---	---	---	---	---	---
Lower Bound	-45.1%	-24.1%	-42.7%	-22.4%	-8.16%	-33.3%
Upper Bound	37.0%	37.0%	137%	95%	8.27%	65.2%

As can be seen from Table 9, service life is a very critical variable in estimating the value of the USACE capital stock value. The estimated range of possible service lives results in relative lower and upper bounds that are 33% below and 65% above the baseline capital stock value estimate of $197 billion. This large range illustrates the large amount of uncertainty present in the capital stock value estimates. An improved understanding on structure service life would be the most effective method for reducing this uncertainty.

4.4 Sensitivity Analysis of Hyperbolic β Assumptions

This section examines the sensitivity of the capital stock estimate with respect to the values used for the hyperbolic β (i.e., deterioration) parameter.[21] As mentioned earlier in this report, observation of USACE capital stock inventory indicates that the most appropriate age-efficiency profile is a hyperbolic function with a β factor between zero and one ($0 < \beta < 1$). These boundaries are necessary to constrain the hyperbolic decay function to the set of functions that reasonably reflect the physical decay being modeled. Additionally, BEA recommends to use β within the range of 0.5 and 0.75 OECD (2009). The value given to β shapes the hyperbolic decay function as described in Section 2.

This study uses a beta factor of 0.6 for the Flood Risk Management, Multipurpose, and MR&T functional categories; 0.5 for the Navigation functional category; and 0.0 or a straight-line age-efficiency pattern for Navigation Dredging. To understand how β assumptions impact the PIM estimate of the USACE capital stock, the upper and lower β bounds of the BEA recommended range of 0.5 to 0.75 were applied to each of the functional categories except dredging, which is assumed to follow a linear age-efficiency profile. The results are shown in Table 10 and Table 11. Table 10 shows the capital stock values for different β assumptions, and Table 11 shows the percent change from the baseline.

Table 10: β Sensitivity Analysis (Billions 2016 $)

Efficiency Profile (Baseline β)	Navigation (w/o dredging) (0.5)	FRM (0.6)	MP (0.6)	MR&T (0.6)	Navigation Dredging (0)	Total ---
Baseline	$64.9	$75.9	$32.6	$15.2	$8.09	$197
Lower Bound (β = 0.5)	$64.9	$70.7	$29.4	$14.2	$8.09	$187
Upper Bound (β = 0.75)	$78.8	$86.4	$39.7	$17.4	$8.09	$230

[21] See Harper (1982) for a discussion of the sensitivity of productive capital stock to variations of the beta function.

Table 11: β Sensitivity Analysis (% change from Baseline)

Efficiency Profile (Baseline β)	Navigation (w/o dredging) (0.5)	FRM (0.6)	MP (0.6)	MR&T (0.6)	Navigation Dredging (0.0)	Total ---
Lower Bound (β = 0.5)	---	-6.82%	-10.0%	-7.00%	---	-4.83%
Upper Bound (β = 0.75)	21.3%	13.9%	21.6%	14.0%	---	17.0%

The capital stock value, both for individual functional categories and the combined total, is less sensitive to changes in β within the range defined by OECD (2009) than to the predicted ranges in service lives.

4.5 Sensitivity Analysis Conclusions

To provide a wider range for report results, an additional sensitivity analysis was conducted. The results are summarized in Table 12 and Table 13. Table 12 summarizes the magnitude of the results from an analysis of the impact of the changes in service life applied in Section 4.3 coupled with a compounding changes in beta applied in Section 4.4, and Table 13 summarizes the accompanying percentage changes that result. The estimated upper bounds defined for service life coupled with an upper bound β value of 0.75 results in an 89% increase in the estimated value of the capital stock, almost doubling the baseline value of $197 billion. The estimated lower bounds defined for service life coupled with the lower β value of 0.5 across all functional categories results in almost a 37% decrease in the estimated value of the capital stock value. There are two specific conclusions that can be drawn from this sensitivity analysis: (1) service life is the most critical assumption that influences the level of the capital stock, and (2) compounding changes in multiple parameters of the model magnifies the impact on the capital stock estimate. Despite the uncertainty observed in estimating the service life especially, the overall conclusions remain the same. The capital stock value of the USACE infrastructure inventory is decreasing due to decreasing investment.

Table 12: β and Service Life Sensitivity Analysis (Billions 2016 $)

Efficiency Profile	Navigation (w/o dredging)	FRM	MP	MR&T	Navigation Dredging	Total
Baseline	$64.9	$75.9	$32.6	$15.3	$8.09	$197
Upper Bound	$105.0	$133.0	$89.6	$34.4	$8.76	$371
Lower Bound	$35.6	$53.9	$16.9	$11.0	$7.43	$125

Table 13: β and Service Life Sensitivity Analysis (% change from Baseline)

Efficiency Profile	Navigation (w/o dredging)	FRM	MP	MR&T	Navigation Dredging	Total
Upper Bound	61.5%	76.0%	175%	126%	8.27%	88.6%
Lower Bound	-45.1%	-29.0%	-48.1%	-27.9%	-8.16%	-36.5%

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Section 5
Findings and Conclusions

This section presents findings of the calculation and sensitivity analysis, making key observations and providing an abbreviated discussion of opportunities to advance this analysis in the future.

5.1 General Findings

The primary purpose of this study is to estimate the USACE capital stock value, building upon the work and findings of previous studies. As an addition to previous reports, this study employs a sensitivity analysis to evaluate the effect of changes in asset service life, age-efficiency profile, and the hyperbolic β rate of decline function on capital stock. This study also investigated how to extend analysis to the evaluation of USACE capital stock value to an analysis by business lines. Efforts to evaluate capital stock value by business line were unsuccessful due to an incomplete historical record and a large percentage of unassigned expenditures in the OMBIL database. Future capital stock efforts will continue to investigate ways to disaggregate the USACE capital stock to business lines. This study also attempted to investigate the disaggregation of the USACE capital stock to the division and district level, but data limitations prevented the development of defensible estimates. Future capital stock efforts will continue to investigate ways to disaggregate the USACE capital stock to business lines and to divisions and districts.

Figure ES-2 presents the summary of USACE capital stock value derived from this study. The 2016 value of the capital stock is estimated to be $197 billion. This value represents a decline of 35.2% from the stock's highest value of $304 billion at its 1982 apex. The service life assumption of 60 years for the Flood Risk Management, Multipurpose, and MR&T functional categories used in this analysis portends that much of the investments made in the 1950s and represented in the current stock shown in Figure ES-2 are in the process of exiting the portfolio. A similar observation can be made with respect to Navigation investments (75-year service life assumption) in the late 1930s and early 1940s. More importantly, to the degree that the assumptions built into the PIM accurately reflect the reality of the actual physical infrastructure being modeled, it can be assumed that as these investments age and deteriorate, the services that the underlying physical infrastructure being modeled provide to the nation will degrade unless replaced or rehabilitated.

Figure 22 shows the pattern of net USACE capital changes over the period 1928 to 2016. Net USACE capital additions are calculated as the difference between USACE investment and retirements and deterioration. Over time, as investments have declined and deterioration and retirement of investments has increased due to hyperbolic deterioration rates and more investments reaching their assumed service life, net USACE capital changes have become negative, indicating that deterioration plus retirements exceed investments. Figure ES-1 of this report shows the historical USACE investment by functional category. Since the late 1960s, investments have been in decline. Beginning in the early 1980s, the combination of the decline in investments and increase in deterioration and retirements coalesced to result in a sustained period during which deterioration plus retirements exceeded investments. This coincided with the point in time when the USACE capital stock estimate began its sustained period of decline as shown in Figure ES-2.

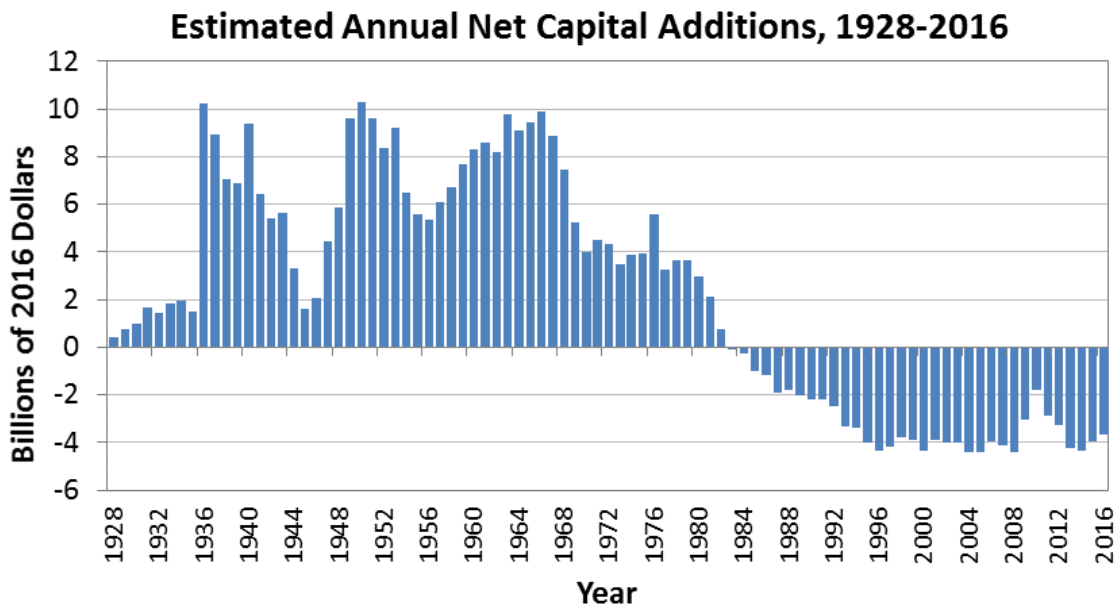

Figure 22
Year-to-year USACE Capital Stock Changes, 1928 to 2016

5.2 Comparison to 2011 Capital Stock Estimate

This section provides a comparison of the previous 2011 capital stock estimate updated to 2016 prices to an estimate of the 2011 capital stock (in 2016 prices) using the data from this report. Both studies use the same service life and beta function assumptions. Table 14 provides a comparison of the 2011 estimate, updated to 2016 dollars, compared to the current study estimate of what the capital stock would have been in 2011 using the current data. The overall estimates are close (within 1%). The slight differences are due to the availability of more recent and updated data.

Table 14: Comparison of 2011 and 2016 Capital Stock Value Estimates (Billions 2016 $)

Scenario	Navigation (w/o dredging)	FRM	MP	MR&T	Navigation Dredging	Total
Previous Estimate for the 2011 Capital Stock	$67.1	$78.8	$44.6	$16.5	$8.9	$218
Current Estimate for 2011 Capital Stock	$69.0	$78.0	$42.2	$17.2	$8.03	$216

5.3 Key Observations

Findings and key points to be drawn from this study are:

- The estimate of the USACE capital stock value exhibits the greatest sensitivity to the service life input parameter. The sensitivity analysis performed for this study estimated uncertainty bounds about the baseline capital stock value from $131 to $325 billion. This large range of uncertainty also translates to uncertainty in the investment needs to maintain current USACE capital stock value. Gaining a better understanding of USACE structure service lives could significantly decrease this uncertainty.

- Since the early-1980s, the estimated capital stock value has declined by 35.2%. The infrastructure continues to generate benefits that contribute to the nation's safety, quality of life, and economic competitiveness, as discussed in detail in the companion report to this study, *Estimating Benefits to the Nation Produced by the US Army Corps of Engineers Civil Works Program*. At some point, if USACE capital stock deterioration and retirement continues to exceed new investment, the Civil Works water resources infrastructure will deteriorate to a level whereby these benefits will begin to diminish, maintenance costs will increase, and services will erode. Replenishing the stock of deteriorated infrastructure will not be simple and will take time. Future investments will have to be evaluated in the context of future benefits and costs.

- The estimated USACE capital stock value peaked in 1982 at $304 billion in 2016 dollars. Since then, it has declined at about an average annual rate of 1.38% through 2016. The 2016 USACE capital stock estimated value is $197 billion, or approximately what it was between 1961 and 1962. The current U.S. population of about 324 million is over 70% greater than the estimated U.S. population in 1963 of 189 million. Therefore, while potential demand may have increased since the 1960s, USACE productive capacity has not.

- From 1982 to 2016, the USACE capital stock estimated value decreased by an average of $3.2 billion each year. If the average annual rate of decline observed over the past 34 years persists, USACE capital stock will have a value of $152 billion or approximately half its peak value by the year 2030.

- Under the current study assumptions, an additional $23.9 billion investment or about $2.4 billion annually over the next 10 years would be needed to sustain the capital stock value near its current level (see Figure ES-2). Anything less will result in further decline over that time frame. This would imply over a 50% increase of the USACE annual expenditure on its capital stock.

- Table 15 provides a more detailed breakdown of the investment required by function category over the next 10 years to maintain the current level of capital stock by functional category.

Table 15: Expenditures Needed Over the Next 10 Years to Maintain the Capital Stock (M$)

FY	Navigation (w/o dredging)	FRM	MP	MR&T	Navigation Dredging	Total
2017	$835	$976	$420	$196	$104.	$2,531
2018	$824	$963	$414	$194	$103	$2,498
2019	$814	$951	$409	$191	$101	$2,466
2020	$803	$939	$404	$189	$100	$2,434
2021	$793	$927	$399	$186	$98.8	$2,403
2022	$783	$915	$393	$184	$97.6	$2,372
2023	$773	$903	$388	$181	$96.3	$2,342
2024	$763	$891	$383	$179	$95.1	$2,312
2025	$752.8	$879.9	$378.4	$176.8	$93.8	$2,282
2026	$743.1	$868.6	$373.5	$174.5	$92.6	$2,252

5.4 Relationship of Findings to Estimate of Benefits Produced by USACE Water Resources Infrastructure

The findings of the analysis of USACE water resources capital stock suggest that investments in USACE water resources infrastructure have not kept pace with the assumptions of deterioration and retirements built into the PIM model. Consequently, the estimated capital stock value of that infrastructure has shown a pattern of decline since the 1980s. As noted in the introduction to this report, a companion report has been produced that has estimated the benefits to the nation produced by USACE water resources infrastructure in 2015. The findings of this analysis suggest that these benefits are nothing short of stellar. For 2015, the net National Economic Development benefits were estimated at over $60 billion, and returns to the U.S. Treasury were estimated at over $8 billion (USACE 2017)[22]. During the past five years, the value of produced by USACE Civil Works programs – as measured by NED benefits and revenues generated to the Treasury – has been fairly stable. If capital value had been maintained, it is likely that the NED benefits and revenues generated could have been greater.

Given the findings of a declining capital stock, and concurrent robust and stable benefit outputs from this capital stock, the question must be asked of the relationship of these findings. Does one contradict the other? How can the findings be reconciled? What implications may flow from the two sets of findings? Two conclusions seem especially relevant:

- It is possible, even likely, that PIM assumptions for service life and deterioration patterns may misstate the actual rate of deterioration and retirement of the USACE capital stock. Though major rehabilitation funding is incorporated as a component of the capital stock estimate, O&M funding has continually increased as a percentage of overall USACE appropriations over time, suggesting that maintenance (both routine and major) is an important focus in USACE capital stock management and that the delivery of benefits is costing more in terms of annual maintenance.

- It is also possible, even likely, that the performance provided by USACE water resources infrastructure is increasingly at risk from old and deteriorating infrastructure that may be approaching the end of its service life. As the capital stock value continues to decline, USACE will eventually reach a tipping point at which benefits begin to decline.

Could there be a lag between impacts to benefits and the decline in capital stock value? Is it possible that benefits would have been higher if capital stock had not deteriorated? Simple logic infers that a loss in the value of the capital stock portfolio would translate into a reduction in benefits over time. However, this inference is not appropriate given the scope and limitations of the methodologies used in the two studies. One is based on a time series of investments and confers the percentage loss of a productive unit of capital stock each year after it is put into place. The benefits report uses different units of measure that are based on or approximations of a monetized value of the services generated by the infrastructure comprising the capital stock inventory in a given year.

Both the concepts of time and units of measure are different between the two methodologies, making a simple comparison of their findings misleading at the least or incorrect at worst. Consequently, the two reports are insightful on their own but not an appropriate basis to form a simple benefit-to-cost comparison used to evaluate future investment decisions. This Capital stock study shows a value decline since 1982 (thirty four years through 2016 whereas the VTN study estimates benefits only for recent years (5-10 years through 2015 depending on the business line).

Nevertheless, the general trends observed in both the current study and the value to nation report should not be taken lightly. A constant benefit stream is not sustainable under a declining capital stock value. Future

[22] See the Value to the Nation Report (USACE 2017) for additional analysis comparing the capital stock to NED benefits.

investigations should focus on the impact of maintenance (both routine and major) as well as maintenance deferral on capital stock deterioration rates. The relationship between benefits and capital stock value should also be studied more closely. If USACE is to remain a leader in water resources management, it must better understand the state and value of its infrastructure and how these factors impact benefits.

5.5 Data Limitations

Several places in this report make mention of limitations placed on the USACE capital stock estimate as a result of insufficient or unavailable data. For example, major rehabilitation funding data prior to 1977 were unavailable but were estimated for the period 1936 through 1977 as described in Section 2.4.2. Section 2.4.3 of this report also points to the uncertainty of historical expenditure data, calling attention to the differences in accounting methodologies used during different time periods. Furthermore, the uncertainty of the capital stock estimate with respect to the key assumptions of service life and the retirement profile has also been acknowledged in this report. Additionally, physical data allowing for the modeling of asset retirements over time were not available. Such physical data would improve the service life assumption by basing it on actual USACE asset retirements.

One conclusion reached as part of this effort is that data limitations present an obstacle in developing PIM assumptions that reflect the actual behavior and characteristics of assets in the USACE portfolio. Assumptions applied to PIM were informed through a literature review, consideration of conclusions from past estimates, and the authors' best judgments vetted by appropriate USACE personnel. The key to improving these assumptions is in acquiring data that would allow for the disaggregation of the USACE Civil Works water resources infrastructure inventory into cohorts of assets with similar function and purpose. Necessary data would include the project's primary purpose, age, year removed from service if no longer in service, net present value, and historical investments. A disaggregated inventory containing the aforementioned USACE-specific empirical data would allow for the development of improved PIM assumptions. These data would add significant value to the USACE capital stock estimate and should be considered when developing future updates.

5.6 Opportunities for Further Improvements in Estimating Capital Stock Value

This section provides a discussion of both the limitations encountered and the opportunities for improvement regarding the current estimate of the USACE capital stock value. Addressing the issues outlined in this section would improve both the process for updating future estimates and the quality of the estimates derived.

The PIM is a well-established methodology used to evaluate the productive capacity of a capital stock portfolio. Confidence in and accuracy of its results are based on the quality of the data and assumptions used in the calculation. These data are a time series of capital expenditures, and these assumptions are the service life and age-efficiency profile of the inventory being evaluated. All three offer opportunities for improvement as follows:

5.6.1 Capital Data

Bulk capital data are available for each year covering the period of study from 1928 to the 2016, but it is uncertain if the conventions used to define capital expenditures for each year are consistent over this period. Variations in the convention will directly affect the outcome of the analysis. There is an opportunity to improve the analysis in the future by confirming the conventions used to sum the value of capital expenditures made each year are consistent or by making corrections to these values as needed.

Additional work is needed to evaluate how well USACE accounting rules and practices align with the definition of capital used by the OECD to conduct PIM calculations. As defined by OECD, the PIM evaluates a

time series of capital expenditures and the effect time has on its productive capacity. OECD approaches this phenomenon as follows:

> *Consumption of **fixed capital** is the decline, during the course of the accounting period, in the current value of the stock of fixed assets owned and used by a producer as a result of physical deterioration, normal obsolescence or normal accidental damage.* (OECD 2009)

In terms of accounting for related expenditures, the Federal Accounting Standards Advisory Board (FASAB) approaches the definition of capital improvements as follows:

> *Maintenance and repairs are activities directed toward keeping fixed assets in an acceptable condition… Maintenance and repairs, as distinguished from capital improvements, exclude activities directed towards expanding the capacity of an asset or otherwise upgrading it to serve needs different from, or significantly greater than, its current use.* (FASAB 2011)

The key issue to consider is to what extent maintenance and repair costs are not included in the sum of capital expenditures reported each year. The current analysis assumes USACE accounting practices are consistent with OECD and FASAB intentions for the purposes of the PIM calculation. Confirmation or clarification of this assumption would improve the credibility of the PIM calculations reported.

5.6.2 Service Life

The service life, in terms of PIM, is the average age when the productive capacity of the original capital investment is exhausted. The service life assumptions used in the PIM analysis performed for this study makes a single assumption for the entire functional category inventory. This assumption is made while acknowledging that many investments within a given functional category do not have the same service life. This recognition introduces an opportunity for improvement. As a low level of effort, a review of the USACE inventory could be performed to assign projects and/or assets into groups and subgroups to derive ***mean service life*** estimates for investments in each asset group within a functional category to be used in the capital stock calculation using expert elicitation panels. As an alternative, empirical studies could be made using this group and subgroup structure to replace estimates of service life with an auditable analysis. It is believed this second course of action would provide much greater benefits given this analysis would also directly support other important USACE objectives such as budget analysis and recapitalization projections.

5.6.3 Age-Efficiency Profile

The age-efficiency profile is the PIM's analog to the degradation curve used in some condition assessments. Thus, improvements to this assumption may also provide direct benefits to other USACE objectives. Using the same asset group concepts introduced above, empirical studies of sample USACE data could be conducted to approximate the capital, maintenance, repair, and operations cost patterns for each. Basic research efforts supporting this report found little or poorly substantiated information related to the age-efficiency profile of USACE capital stock assets. One method to determine the age-efficiency profiles of USACE assets would be to compile and analyze life-cycle cost data on a sample inventory dataset and perform a regression analysis to fit a curve to approximate the age-efficiency profile of each asset group considered. This analysis could also double as an effort to document life-cycle cost models for all major USACE asset groups and would have application in agency-wide budget development and analysis, funds allocations, and recapitalization projections.

5.6.4 Defining the Problem Statement

There remains one additional area that would improve the credibility of this analysis, which is to better define the problem statement being addressed. An improved definition would alter the analysis by requiring that the flow of capital expenditures and the inventory being considered to be better defined. For example, is the analysis intended to evaluate the capital stock USACE is responsible for maintaining or is it intended to

evaluate all the capital stock built by USACE during the period of study?[23] This difference is important because if it is the former, then the capital expended on assets built by USACE and turned over to another entity should be removed from the analysis in its entirety, including original construction costs. If, on the other hand, USACE turns over a capital asset to another entity that then makes additional capital expenditures on it, then these expenditures should be incorporated into the analysis to truly reflect the productive measure of the capital stock portfolio. In the first case, the problem statement may better align with arguments USACE is making, supporting budget requirements to maintain its capital stock inventory. In the second case, the problem statement may better align with arguments USACE may make supporting a broader national strategy related to water resources civil works infrastructure. In either case, the lack of a clear problem statement makes it difficult to determine the correct boundary conditions on the capital expenditures to be used in relation to the evaluation of certain solution sets to be considered.

5.6.5 Overall Data Management Improvements

The issue of estimating capital stock value has been of concern to USACE since at least the mid-1990s and the Federal Infrastructure Study. Estimates have been made for years 1990, 1999, and 2011. Unfortunately, the extended time between these updates has prevented a sustainment of progress in the methods and data employed to estimate USACE capital stock. Currently, there is a broad emphasis on improving asset management and the development of an overall strategy to ensure that USACE infrastructure is adequately capitalized to meet the demands that will be placed on it into the future. It is likely that more information about the state of USACE capital stock will be required. Given the likely increased emphasis for more and better data on asset condition and performance, an opportunity exists to create a sustained capability for improved asset management data. It is recommended that a formal **Asset Management Data Improvement Workgroup** be formed and funded with the mission to ensure that USACE has the correct methods and data necessary to estimate the condition and performance of its infrastructure.

5.7 Needed Improvements in Capital Stock Estimation Procedures

This study has shed light on the need for improvements to the USACE Civil Works Water Resources capital stock estimate. The utility of the capital stock estimate derived using PIM has been called into question due to the lack of detail it provides for focused portfolio management and recapitalization decision making. Additionally, the PIM method is top down, whereas individual decisions are bottom up with respect to existing capital stock and new investment. Issues regarding data availability and quality have prohibited a useful disaggregation of USACE assets that would allow for a more detailed analysis. Furthermore, the infrequency of the estimate has led to an atrophied focus on the purpose and usefulness of the estimate.

While PIM is the internationally accepted approach to estimating the capital stock value of entities with large portfolios of assets, it is also recognized that it is a top-down metric that provides a gross-level estimate of capital stock that is most useful for calling attention to broad investment issues at a gross level. Thus, PIM is not well suited for detailed capital budgeting and investment portfolio management.

To be equipped to perform more detailed portfolio management, a more fine-grained and bottom up procedure to examine infrastructure condition and benefits being produced by USACE infrastructure is needed. The USACE asset management initiative is an effort to focus more closely on the condition and performance of existing infrastructure to make decisions regarding future investments as well as strategic decisions with respect to operations and maintenance appropriations. Applying the data and resources associated with this initiative likely would benefit the capital stock estimation procedure.

[23] Much of the flood risk management infrastructure built by USACE since at least the 1986 Water Resources Development Act and the changes in cost sharing rules has been local protection projects, which are turned over to the local sponsor for operation and maintenance at the completion of the cost-shared project development and construction phase.

It is recommended that an Infrastructure Portfolio Analysis and Management System (IPAMS) be developed, with a focus on improving data for analysis of the USACE portfolio that will be useful for detailed portfolio management and recapitalization decision making. An integrated project team composed of USACE staff from various arms of USACE should guide the IPAMS. This team should focus on improvements to the data and methods to develop metrics that are most appropriate to the portfolio characteristics and portfolio management and investment needs of USACE. Key questions that the team should address include:

- Can there be improvements to the service life assumptions of similar assets by analyzing the age and types of assets/projects that have been removed from service or retired?
- Can the service life assumption be improved with more detailed data and analysis of the projects and assets in service?
- Can the deterioration assumption be improved by an analysis of asset condition over time?

5.8 Future Work and Study Improvements

- The effect of routine and major maintenance expenditures on the capital stock value will be explored. The relationship between deferred maintenance and the capital stock value will also be investigated.
- The capital stock team will work with different districts to evaluate specific project and asset capital stock value trends.
- A continued effort will be made to improve data quality and resolution to improve the capital stock value estimates—especially to better understand service life, deterioration, and retirement assumptions.
- Investigate how to better incorporate uncertainty into estimates.
- Further investigate the relationship between USACE capital stock value and value to nation benefits trends.

Section 6
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Appendix A
Glossary

Age-Efficiency Profile – Describes the pattern and rate at which an asset's or class of assets' productive capacity deteriorates over its defined service life. For example, the hyperbolic age-efficiency profile is a type of age-efficiency profile in which an asset's productive capacity declines at a slow rate in the first years of its service life and at increasingly faster rates toward the end of its service life.

Asset – Long-lived entity with productive capacity, obtained from an investment or capital expenditure. For USACE, assets include dams, levees, locks, improved channels, and power houses. Assets are also denoted as infrastructure because they facilitate production of other goods and services.

Book value – The value at which an asset is carried on a balance sheet and calculated by taking the cost of an asset minus the accumulated depreciation.

Bureau of Economic Analysis (BEA) – An agency in the U.S. Department of Commerce that provides important economic statistics to support policy development and economic decision making.

Capital Stock Value – The value of a particular type of asset surviving from past periods that has been corrected for its loss in productive capacity.

Constant Dollars – An adjusted dollar value used to account for inflation in order to compare dollars from one period to another. Dollars in previous years (i.e., nominal dollars) are expressed in terms of dollars of an arbitrary year (e.g., present day).

Deterioration – The decline in productive capacity over time.

Expenditure – Dollars dedicated to creating capital (e.g., assets and/or infrastructure) with productive capacity (synonymous with "investment").

Fixed Capital – The portion of total capital that is invested in fixed assets (such as land, buildings, vehicles, and equipment) that remains in service for an extended period, or at the very least, for more than one accounting period (synonymous with "capital stock").

Major Rehabilitation – Investment or maintenance sufficient to effectively "restart" an asset's service life

Mean Service Life – The average duration over which a group or type of assets continues to maintain some level of productive capacity.

Nominal Dollars – Dollar values expressed in fixed nominal monetary terms in a given year or series of years. Nominal dollars reflect values for that year and are not adjusted to account for changes in purchasing power over time.

Organization of Economic Cooperation and Development (OECD) – International economic organization comprised of 34 countries founded in 1961 to stimulate economic progress and world trade.

Perpetual Inventory Method (PIM) – Approach that estimates capital stocks by cumulating flows of investment, corrected for retirement and depreciation (in the case of net stocks) or efficiency losses (in the case of productive stocks).

Productive Capacity – The potential of capital to generate services and benefits given historical investment (i.e., dollars dedicated to creating capital with productive capacity), asset deterioration over time, maintenance, and rehabilitation (i.e., investment or maintenance sufficient to effectively "restart" an asset's service life).

Rate of Decline – Represents the percentage change in an asset's productive capacity when age moves by one unit. The β represents the coefficient controlling the rate of decline for the hyperbolic age-efficiency profile.

Recapitalization – Funding intended for major rehabilitation projects and new investment.

Retirement – The act of putting an asset out of service because it has reached the end of its service life.

Service Life – The number of years that an asset is maintained in service with some level of productive capacity.

Simultaneous Exit Mortality Assumption – A pattern of retirement that assumes that all assets are retired from the capital stock at the moment they reach the end of their assumed service life for the type of asset concerned. This assumption does not assume that any assets are retired prior to reaching the service life age nor does it assume that any assets survive after the service life age is reached.

Appendix B
Calculation Examples

This appendix describes a how to make example capital stock calculations using only 5 years of expenditure data for a single functional category. All expenditure amounts were selected arbitrarily and in no way reflect actual USACE water resources investments.

The calculation is described in four steps with screen shots of the Capital Stock Workbook spreadsheet used to illustrate the process.

STEP 1: Setting the input parameters

The "Assumptions and Index - Baseline" tab of the spreadsheet provides an interface that allows the user to set the PIM input parameters. Figure B-1 below shows the input parameters used for this study outlined in red. Under the heading "Deterioration Assumptions," a drop-down menu allows the user to select from a variety of age-efficiency patterns (see Section 4.2 of this report for a description of the age-efficiency patterns available in this menu). Depending on the age-efficiency profile selected, the rate of deterioration can be adjusted in the corresponding cells below. In this example, the hyperbolic function has been chosen, and a beta function value of 0.5 is set. Next, the service life assumption is set to 75 years.

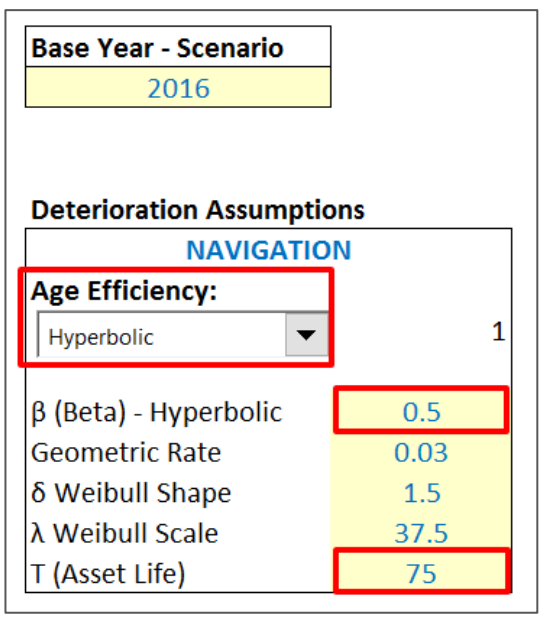
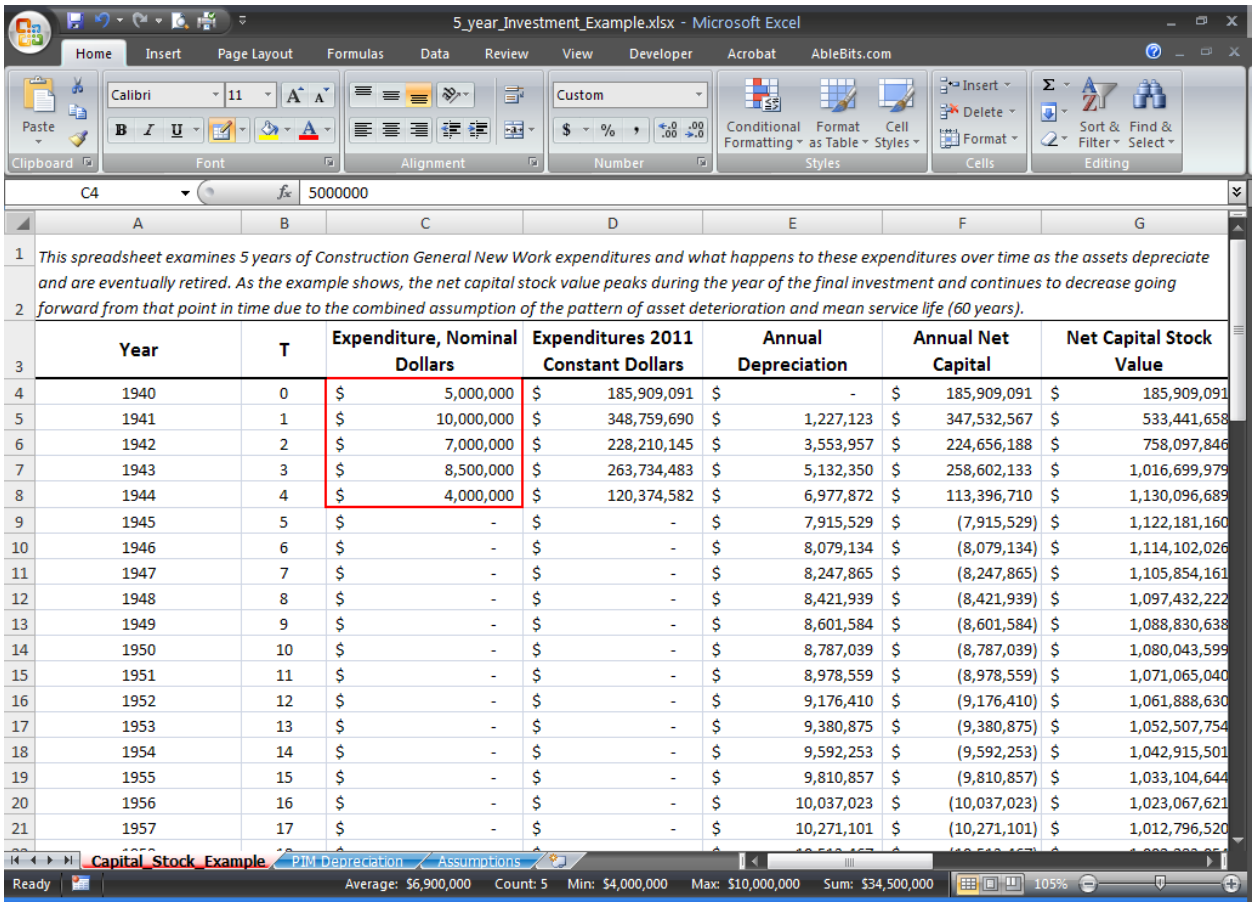


Figure B-1
Capital Stock Spreadsheet Model Assumptions

Step 2: Enter the annual expenditure amount

The first step to calculating capital stock is to collect and compile enter annual expenditures. These expenditures should reflect Construction General new work expenditures that contribute to the capital stock value and will deteriorate over time according to the input parameter assumptions. As additional expenditures are made, capital stock value increases.

In Figure B-2, the cells outlined in red are the annual expenditures input by the user. In column D of this worksheet, nominal expenditures input by the user are adjusted to 2011 constant dollars (or the current year) using the Engineering News-Record Construction Cost Indices (see Figure B-3).



This spreadsheet examines 5 years of Construction General New Work expenditures and what happens to these expenditures over time as the assets depreciate and are eventually retired. As the example shows, the net capital stock value peaks during the year of the final investment and continues to decrease going forward from that point in time due to the combined assumption of the pattern of asset deterioration and mean service life (60 years).

Year	T	Expenditure, Nominal Dollars	Expenditures 2011 Constant Dollars	Annual Depreciation	Annual Net Capital	Net Capital Stock Value
1940	0	$ 5,000,000	$ 185,909,091	$ -	$ 185,909,091	$ 185,909,091
1941	1	$ 10,000,000	$ 348,759,690	$ 1,227,123	$ 347,532,567	$ 533,441,658
1942	2	$ 7,000,000	$ 228,210,145	$ 3,553,957	$ 224,656,188	$ 758,097,846
1943	3	$ 8,500,000	$ 263,734,483	$ 5,132,350	$ 258,602,133	$ 1,016,699,979
1944	4	$ 4,000,000	$ 120,374,582	$ 6,977,872	$ 113,396,710	$ 1,130,096,689
1945	5	$ -	$ -	$ 7,915,529	$ (7,915,529)	$ 1,122,181,160
1946	6	$ -	$ -	$ 8,079,134	$ (8,079,134)	$ 1,114,102,026
1947	7	$ -	$ -	$ 8,247,865	$ (8,247,865)	$ 1,105,854,161
1948	8	$ -	$ -	$ 8,421,939	$ (8,421,939)	$ 1,097,432,222
1949	9	$ -	$ -	$ 8,601,584	$ (8,601,584)	$ 1,088,830,638
1950	10	$ -	$ -	$ 8,787,039	$ (8,787,039)	$ 1,080,043,599
1951	11	$ -	$ -	$ 8,978,559	$ (8,978,559)	$ 1,071,065,040
1952	12	$ -	$ -	$ 9,176,410	$ (9,176,410)	$ 1,061,888,630
1953	13	$ -	$ -	$ 9,380,875	$ (9,380,875)	$ 1,052,507,754
1954	14	$ -	$ -	$ 9,592,253	$ (9,592,253)	$ 1,042,915,501
1955	15	$ -	$ -	$ 9,810,857	$ (9,810,857)	$ 1,033,104,644
1956	16	$ -	$ -	$ 10,037,023	$ (10,037,023)	$ 1,023,067,621
1957	17	$ -	$ -	$ 10,271,101	$ (10,271,101)	$ 1,012,796,520

Figure B-2
Input Annual Construction General New Work Expenditure Data

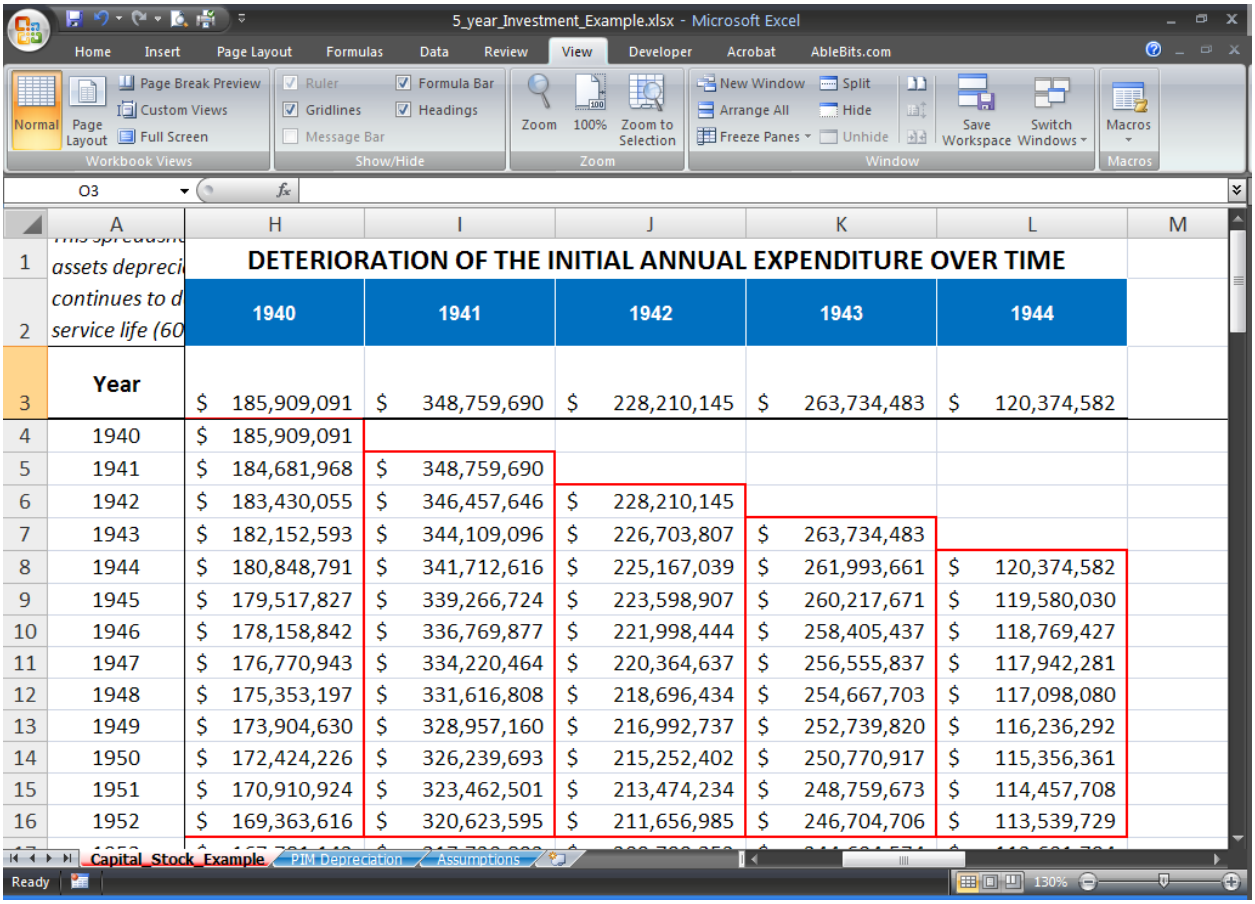
CCI for Inflation

Year	ENR CCI	Index
1944	299	34.58
1945	308	33.57
1946	346	29.88
1947	413	25.03
1948	461	22.43
1949	477	21.67
1950	510	20.27

Figure B-3
Example Construction Cost Indices (CCIs) applied to expenditures to convert them to current year $.

Step 3: Deterioration of Initial Expenditures

Figure B-4 shows how the expenditures input into the worksheet "deteriorate" over time after they are initially input into the spreadsheet model. The rate of deterioration is determined by the service life and beta factor assumptions set in the "Assumptions" worksheet (Step 1). The values in Figure B-4 illustrate the asset depreciation pattern over time using the hyperbolic age-efficiency profile and a service life of 75 years (as defined in Figure B-1). Note that the expenditures do not begin to deteriorate until the year after they were initially made.

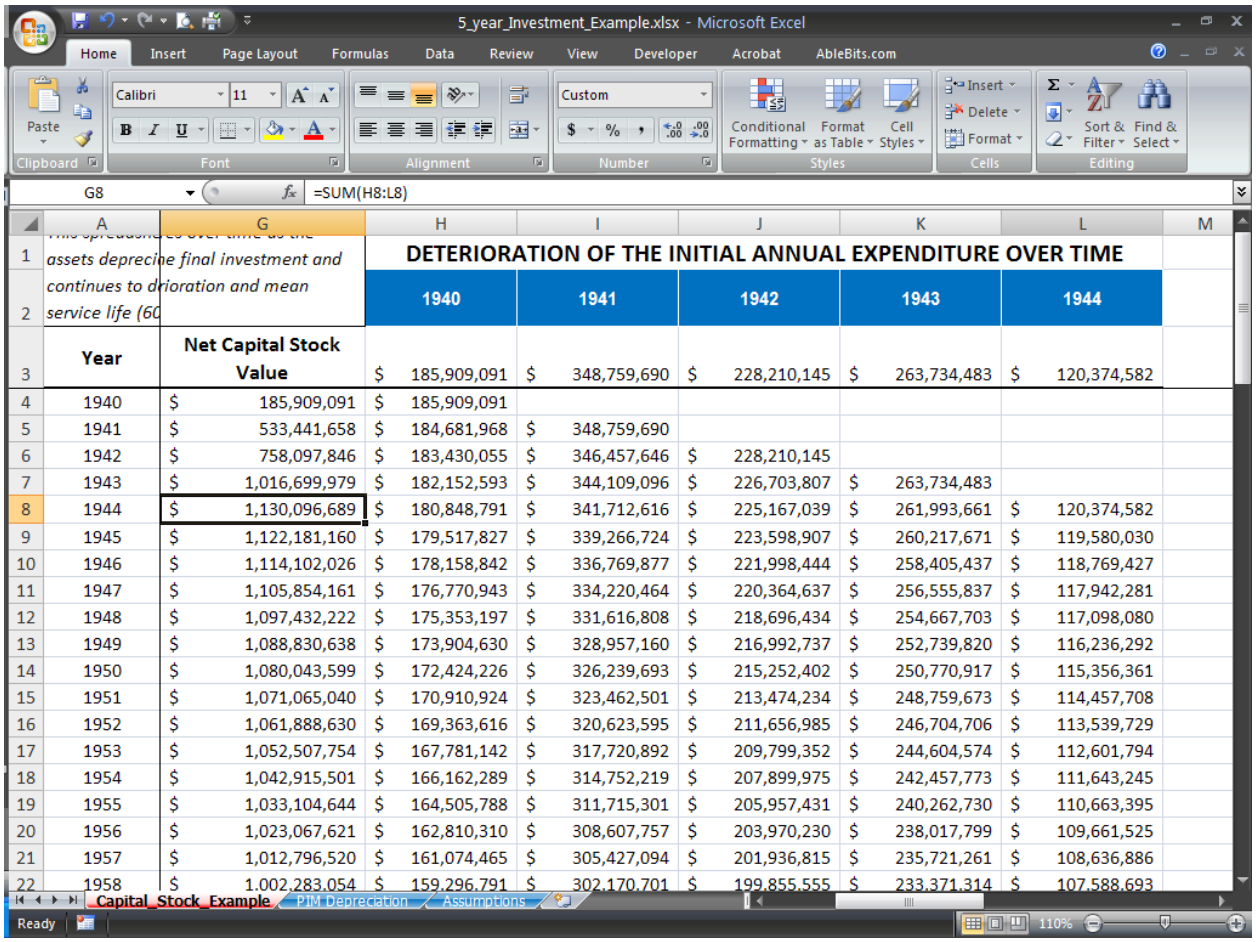


	A	H	I	J	K	L	M
1	*assets depreci*	DETERIORATION OF THE INITIAL ANNUAL EXPENDITURE OVER TIME					
2	*continues to d service life (60*	1940	1941	1942	1943	1944	
3	Year	$ 185,909,091	$ 348,759,690	$ 228,210,145	$ 263,734,483	$ 120,374,582	
4	1940	$ 185,909,091					
5	1941	$ 184,681,968	$ 348,759,690				
6	1942	$ 183,430,055	$ 346,457,646	$ 228,210,145			
7	1943	$ 182,152,593	$ 344,109,096	$ 226,703,807	$ 263,734,483		
8	1944	$ 180,848,791	$ 341,712,616	$ 225,167,039	$ 261,993,661	$ 120,374,582	
9	1945	$ 179,517,827	$ 339,266,724	$ 223,598,907	$ 260,217,671	$ 119,580,030	
10	1946	$ 178,158,842	$ 336,769,877	$ 221,998,444	$ 258,405,437	$ 118,769,427	
11	1947	$ 176,770,943	$ 334,220,464	$ 220,364,637	$ 256,555,837	$ 117,942,281	
12	1948	$ 175,353,197	$ 331,616,808	$ 218,696,434	$ 254,667,703	$ 117,098,080	
13	1949	$ 173,904,630	$ 328,957,160	$ 216,992,737	$ 252,739,820	$ 116,236,292	
14	1950	$ 172,424,226	$ 326,239,693	$ 215,252,402	$ 250,770,917	$ 115,356,361	
15	1951	$ 170,910,924	$ 323,462,501	$ 213,474,234	$ 248,759,673	$ 114,457,708	
16	1952	$ 169,363,616	$ 320,623,595	$ 211,656,985	$ 246,704,706	$ 113,539,729	

Figure B-4
Annual Expenditure Deterioration over Time

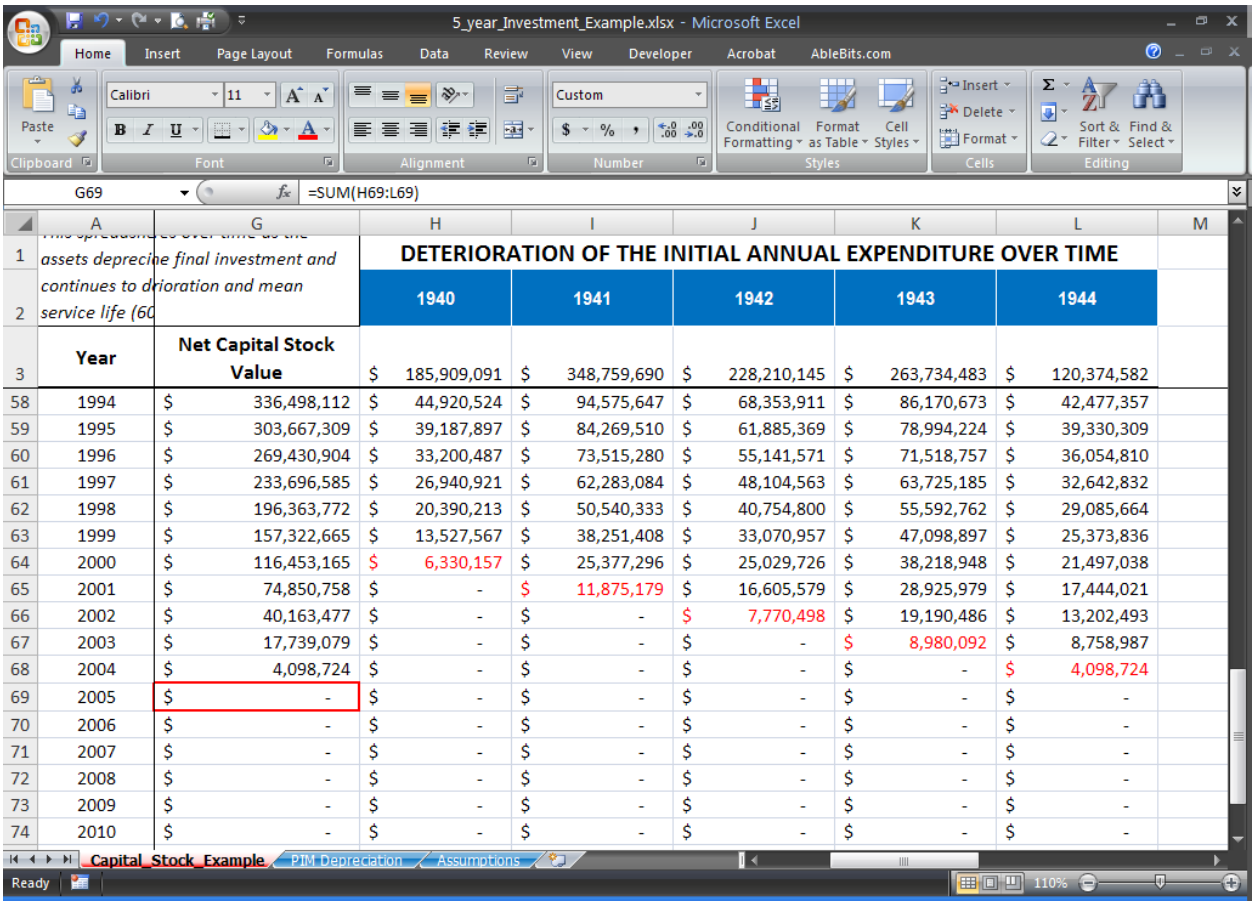
Step 4: Deriving Annual Net Capital Stock Value

The total annual deterioration value is subtracted from the cumulative expenditures to derive the net capital stock value for each year (Figure B-5). In this example, the capital stock value peaks with the fifth and final year of expenditure input (1944). The capital stock value shown in this cell is computed as the sum of the annual expenditures over time, less deterioration value (cells H8:L8). After 1944, when no new expenditures are added, the total capital stock value begins to decline. It reaches zero by 2005, 61 years after the final expenditure was input into the model in 1944 (Figure B-6).



Year	Net Capital Stock Value	1940	1941	1942	1943	1944
		$ 185,909,091	$ 348,759,690	$ 228,210,145	$ 263,734,483	$ 120,374,582
1940	$ 185,909,091	$ 185,909,091				
1941	$ 533,441,658	$ 184,681,968	$ 348,759,690			
1942	$ 758,097,846	$ 183,430,055	$ 346,457,646	$ 228,210,145		
1943	$ 1,016,699,979	$ 182,152,593	$ 344,109,096	$ 226,703,807	$ 263,734,483	
1944	$ 1,130,096,689	$ 180,848,791	$ 341,712,616	$ 225,167,039	$ 261,993,661	$ 120,374,582
1945	$ 1,122,181,160	$ 179,517,827	$ 339,266,724	$ 223,598,907	$ 260,217,671	$ 119,580,030
1946	$ 1,114,102,026	$ 178,158,842	$ 336,769,877	$ 221,998,444	$ 258,405,437	$ 118,769,427
1947	$ 1,105,854,161	$ 176,770,943	$ 334,220,464	$ 220,364,637	$ 256,555,837	$ 117,942,281
1948	$ 1,097,432,222	$ 175,353,197	$ 331,616,808	$ 218,696,434	$ 254,667,703	$ 117,098,080
1949	$ 1,088,830,638	$ 173,904,630	$ 328,957,160	$ 216,992,737	$ 252,739,820	$ 116,236,292
1950	$ 1,080,043,599	$ 172,424,226	$ 326,239,693	$ 215,252,402	$ 250,770,917	$ 115,356,361
1951	$ 1,071,065,040	$ 170,910,924	$ 323,462,501	$ 213,474,234	$ 248,759,673	$ 114,457,708
1952	$ 1,061,888,630	$ 169,363,616	$ 320,623,595	$ 211,656,985	$ 246,704,706	$ 113,539,729
1953	$ 1,052,507,754	$ 167,781,142	$ 317,720,892	$ 209,799,352	$ 244,604,574	$ 112,601,794
1954	$ 1,042,915,501	$ 166,162,289	$ 314,752,219	$ 207,899,975	$ 242,457,773	$ 111,643,245
1955	$ 1,033,104,644	$ 164,505,788	$ 311,715,301	$ 205,957,431	$ 240,262,730	$ 110,663,395
1956	$ 1,023,067,621	$ 162,810,310	$ 308,607,757	$ 203,970,230	$ 238,017,799	$ 109,661,525
1957	$ 1,012,796,520	$ 161,074,465	$ 305,427,094	$ 201,936,815	$ 235,721,261	$ 108,636,886
1958	$ 1,002,283,054	$ 159,296,791	$ 302,170,701	$ 199,855,555	$ 233,371,314	$ 107,588,693

Figure B-5
Deriving the Net Capital Stock Value



G69 =SUM(H69:L69)

	A	G	H	I	J	K	L	M
1	*assets deprecine final investment and*		DETERIORATION OF THE INITIAL ANNUAL EXPENDITURE OVER TIME					
2	*continues to drioration and mean service life (60*		1940	1941	1942	1943	1944	
3	Year	Net Capital Stock Value	$ 185,909,091	$ 348,759,690	$ 228,210,145	$ 263,734,483	$ 120,374,582	
58	1994	$ 336,498,112	$ 44,920,524	$ 94,575,647	$ 68,353,911	$ 86,170,673	$ 42,477,357	
59	1995	$ 303,667,309	$ 39,187,897	$ 84,269,510	$ 61,885,369	$ 78,994,224	$ 39,330,309	
60	1996	$ 269,430,904	$ 33,200,487	$ 73,515,280	$ 55,141,571	$ 71,518,757	$ 36,054,810	
61	1997	$ 233,696,585	$ 26,940,921	$ 62,283,084	$ 48,104,563	$ 63,725,185	$ 32,642,832	
62	1998	$ 196,363,772	$ 20,390,213	$ 50,540,333	$ 40,754,800	$ 55,592,762	$ 29,085,664	
63	1999	$ 157,322,665	$ 13,527,567	$ 38,251,408	$ 33,070,957	$ 47,098,897	$ 25,373,836	
64	2000	$ 116,453,165	$ 6,330,157	$ 25,377,296	$ 25,029,726	$ 38,218,948	$ 21,497,038	
65	2001	$ 74,850,758	$ -	$ 11,875,179	$ 16,605,579	$ 28,925,979	$ 17,444,021	
66	2002	$ 40,163,477	$ -	$ -	$ 7,770,498	$ 19,190,486	$ 13,202,493	
67	2003	$ 17,739,079	$ -	$ -	$ -	$ 8,980,092	$ 8,758,987	
68	2004	$ 4,098,724	$ -	$ -	$ -	$ -	$ 4,098,724	
69	2005	$ -	$ -	$ -	$ -	$ -	$ -	
70	2006	$ -	$ -	$ -	$ -	$ -	$ -	
71	2007	$ -	$ -	$ -	$ -	$ -	$ -	
72	2008	$ -	$ -	$ -	$ -	$ -	$ -	
73	2009	$ -	$ -	$ -	$ -	$ -	$ -	
74	2010	$ -	$ -	$ -	$ -	$ -	$ -	

Figure B-6
Capital Stock Value Declines to Zero 61 Years after the Final Expenditure is Input into the Model

Institute for Water Resources

SPREADSHEET USERS GUIDE

CDM Federal Programs Corporation (CDM Smith)

Estimating USACE Capital Stock, 1928 to 2016

USACE Institute for Water Resources
Contract # W912HQ-16-D-0003

March 2018

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Capital Stock Microsoft Excel Spreadsheet

Purpose

The Capital Stock Microsoft Excel spreadsheet is a model designed to calculate the capital stock within the Corps' inventory of Civil Works water resources infrastructure using the perpetual inventory method (PIM). The purpose of this document is to describe the organization, methodology, and functionality of the spreadsheet model.

Organization

This spreadsheet is organized generally into three types of tabs: general data/input tabs, calculation/output tabs for baseline scenario, and tabs associated with a sensitivity analysis. Within the spreadsheet, the general data/input tabs are colored blue. Input tabs primarily contain the data that drive the calculations in the model. Tabs that calculate the results and provide outputs for the baseline scenario are colored orange. The tabs associated with the sensitivity analysis are colored green.

The cells within the sheets are color coded to distinguish their purpose. Yellow cells with blue font are input cells, while numbers in black font are formula driven.

Data

The model is driven by a combination of historical data provided by IWR and more recent data from the OMBIL system. While OMBIL data dates back to 1999, the data appears to be incomplete until 2008. In developing the model, it was viewed as essential to begin transitioning the capital stock calculation to incorporate OMBIL data. As such, the model has been designed to utilize historical data provided by IWR through 2007, and OMBIL data beginning with FY 2008.

A large portion of the OMBIL data includes expenses grouped into an Unknown category, which represent expenses that have not been allocated to a specific functional category. The calculations assume an allocation of the Unknown total to the individual expense categories based on a 25-year average allocation pattern. To the extent the allocation methodology in the model fails to accurately replicate the true spending pattern on capital stock, it will adversely impact the ability to generate accurate estimates by category. This can most easily be remedied by more accurately allocating unknown expenses in the data set to the appropriate functional category.

Description of Tabs in Model

Each of the following subsections describes an individual tab within the Capital Stock spreadsheet model.

Assumption and Index - Baseline

This tab contains the basic assumptions that drive the calculations for the baseline scenario. The user should note that the assumptions pertaining to the sensitivity analyses are in a separate tab.

The assumptions and indices are as follows:

- Base Year (cell B4): This is the current year for which the model will calculate the capital stock. This particularly important as it relates to cost inflation, which utilizes a historical Construction Cost Index published by the Engineering News-Record (ENR CCI).

- Deterioration Assumptions (boxes starting in cell B7): These assumptions relate to the age-efficiency profile and are primarily linked into the PIM Deterioration tab. Each functional category (Navigation, FRM, Multipurpose, MR&T, Navigation Dredging) contains a unique set of inputs.
    - Dropdown Box: The dropdown box defines the age-efficiency profile that the model will use for each functional category. This assumption carries through to the *PIM Deterioration* tab to define the deterioration schedule.
    - Beta (β): The Beta factor is a parameter relevant to the hyperbolic function only. The factor is used to determine the rate of decline for an asset's age-efficiency profile.
    - Geometric Rate: The geometric rate is the parameter in determining the rate of deterioration for the geometric function only. The geometric rate represents the rate of deterioration at which the geometric function compounds over time.
    - Weibull Shape (λ) and Scale (δ): These are input factors for the Weibull function only. The Weibull function is commonly used in reliability engineering in determining failure rates. The scale parameter determines the timeline for which the function extends and the shape parameter determines the slope characteristics of the function. The shape of the function can vary significant based on whether the δ is less than, equal to or greater than 1.
    - T (Asset Life): This is the assumption for the mean service life of the assets, and affects all age-efficiency profiles. The analysis assumes an asset has fully deteriorated at the given T, regardless of the remaining efficiency of a given asset.
- Include Navigation Dredging (cell B20)

  This dropdown allows the user to choose whether to include Navigation Dredging in the analysis as a separate functional category. The default for the baseline scenario is to include it as a part of the calculation, but the Yes/No dropdown enables the user to exclude it if desired.
- Expenditure Lookups Data (starting in cell B25)

  Contained in cells B27:G27, these values are tied to several lookup formulas throughout the model that match data to the appropriate functional category. These inputs should not be changed - doing so will materially impact the integrity of the model.
- CCI for Inflation (starting in cell B29)

  These inputs are the historical Construction Cost Index (CCI) values obtained from the Engineering News-Record. The index column is used to inflate new work to constant dollars, based on the index and the chosen base year (for baseline scenario, 2016). The CCI values represent historical data and should not be changed; however, future years can be added as applicable

PIM Deterioration

This tab details the deterioration schedules for each age-efficiency profile imbedded in the model. The deterioration schedules in Columns B through K represent that active schedules in the model, one for each functional category. The age-efficiency profiles in this sheet are consistent with the options in the *Assumption and Index – Baseline* sheet: Hyperbolic, One-Hoss Shay, Straight Line, Geometric, Weibull and Normal.

The *PIM Deterioration* tab does not contain any user inputs, and any modifications to the assumptions driving the calculations should be set in the *Assumption and Index – Baseline* sheet.

OMBIL Input

This tab contains the information by functional category derived from OMBIL. For the analysis, the model utilizes historical IWR data prior to 2008, and utilizes OMBIL expenditure data for 2008 and future years. Although the OMBIL data goes back to 2006, the data from 2006 and 2007 is incomplete and not useable.

Since a large portion of the OMBIL data includes expenses grouped into an Unknown category, the calculations assume an allocation of the Unknown total to the individual expense categories based on a 25-year average allocation pattern. The allocation disperses the costs of the Unknown category among the Navigation, Flood Risk Management, and Multipurpose project types. The expenditure allocation calculation exists in cells P20:P23.

Major Rehab Data

The *Major Rehab Data* sheet contains historical and estimated major rehabilitation data by functional category from 1936 to 1993. Values prior to 1977 were estimated based upon the observed relationship of major rehabilitation expenditures to Construction General expenditures from 1997 through 1993. The allocation percentages are listed in cells K27:K30. From 1977 through 1993, actual historical data are included by category.

Beginning in 1994, the Corps began to fund the major rehabilitation out of the Construction General account, so is included as part of the totals in the *New Work Data* tab for 1994 and future years.

A more robust discussion related to major rehabilitation expenses can be found in Section 2.4.2 of the report.

New Work Data

This tab contains the Construction General new work expenditure data. Data prior to 2008 is historical data by category provided by IWR. For 2008 and future years, the annual total by category represents the reported expenditures from OMBIL, as well as the allocated amount from the Unknown category based on the proportions defined in cells P20:P23 in the *OMBIL Input* tab.

Expenditure Data Total

The totals in this sheet drive the calculations for the analysis and represent Construction General appropriations. The total expenditures presented in this tab represent the sum of new work and major rehabilitation expenditures. This sheet does not have any user inputs, and is largely built from lookups to the previously referenced tabs.

Business Line Analysis

There are insufficient data available to estimate the USACE capital stock by business line. This worksheet was used in an initial attempt to develop an analysis/estimate of the USACE capital stock value by business line. It accepts expenditure data by business line and uses the relative magnitudes of business line expenditures to develop a business line based estimate of the FY16 capital stock value.

Navigation, Flood Risk Management, Multipurpose, MRT, and Navigation Dredging

These orange tabs contain the capital stock calculations by functional category for the baseline scenario. There are no user input cells in these sheets. The calculations are driven by the inputs in the *Assumption and Index – Baseline* tab, the selected age-efficiency profile in the *PIM Deterioration* tab, and the data from the *Expenditure Data Total* tab.

Total

This is an output tab summarizing the individual functional category sheet calculations for the baseline. Columns B through F provide the total USACE capital stock value by year and functional category, with column G calculating the total capital stock by year. The information in cells A4:G4 represent the total calculated capital stock by category for the selected base year in the assumptions. Cells B7:F7 calculate the percentage each functional category represents of the total 2016 capital stock value estimate.

Columns I through M provide the net annual additions to the capital stock over time, by year and functional category, with Column N capturing the total.

This sheet also contains a variety of graphs summarizing the baseline results, which begin at row 107.

There are no user input cells in this sheet.

Additional Graphs

This is an output tab containing several additional graphs summarizing the information.

Hyperbolic Decay Functions

This worksheet is used to develop graphical report input on different values of the Beta parameter of the hyperbolic decay function.

Sensitivity Console

The *Sensitivity Console* is a sheet that enables the user to make adjustments to various assumptions and inputs, and compare the results. The general inputs mimic those that are described for the *Assumption and Index – Baseline* tab, however the *Sensitivity Console* generates separate results. The user can set the base year, age-efficiency profile, and the related factors for each functional category. These inputs will be unique from the baseline scenario.

The Navigation Dredging and the CCI for Inflation inputs (respectively cells B18 and B21) are tied to the baseline scenario, which are set in the *Assumption and Index – Baseline* tab and linked to cells. The calculations for the sensitivity analysis rely on the expenditure data in the *Expenditure Data Total* tab.

The section of the sheet between rows 139 and 167 shows the summary of the results for both the baseline and the current scenario. The current scenario represents the results of the unique inputs the user has defined in this *Sensitivity Console*. The results compare the total capital stock by functional category, and the percent that each functional group represents to the total.

In column J (row 139), there is a section for "Table of Scenarios". The intent of this section is to allow the user to track the scenarios that have been run and compare the results in a comparison table. The user can copy the results of the current scenario into the peach colored cells and include a description as to the changes in the assumptions.

The remainder of the sheet is an output of the results for the current scenario, including graphs and a summary table summarizing the total capital stock over time for each functional category (similar to the *Total* tab).

PIM Deterioration - Scenario

This includes the deterioration schedules for each age-efficiency profile, linked to the inputs in the *Sensitivity Console*.

Navigation - Scenario, Flood Risk Management - Scen, Multipurpose - Scenario, MRT - Scenario, and Navigation Dredging - Scenario

These tabs contain the capital stock calculations by functional category for the sensitivity analysis. There are no user input cells in these sheets. The calculations are driven by the user inputs in *Sensitivity Console* tab, the selected age-efficiency profile in the *PIM Deterioration - Scenario* tab, and the data from the *Expenditure Data Total* tab.

Total - Scenario

This is an output tab summarizing the individual functional category sheet calculations for the sensitivity analysis. Columns B through F provide the total USACE capital stock by year, by category, with column G calculating the total capital stock by year.

Columns I through M provide the net additions to the capital stock over time, by category, with Column N capturing the total.

This sheet also contains a variety of graphs summarizing the baseline results, which begin at row 100.

There are no user input cells in this sheet.

Updating the Estimate

Note: Prior to updating the estimate, save a copy of the spreadsheet and change the spreadsheet name to indicate the date it is being updated. This will allow the user to maintain the original spreadsheet as a reference and develop an updated spreadsheet for the current fiscal year.

It is also advised that the user review all assumption values for appropriateness as a component to performing the update. See the report "Estimating USACE Capital Stock, 1928 – 2016" for a discussion of the assumptions used.

Step 1: Review Assumptions and Update Input Data in the *Assumption and Index - Baseline* Tab – Yellow cells with blue font indicate the input values for the *Assumption and Index - Baseline* tab. Please see the report "Estimating USACE Capital Stock, 1928 – 2016" for a detailed discussion regarding the assumptions. The CCI data should be updated for each fiscal year update.

Step 2: Update Input Data in the OMBIL Data Tab – The OMBIL database supplies the most recently available expenditures data. Going forward, the OMBIL system will be the most appropriate source for USACE expenditure data by functional category. The user will update the expenditure data in this tab with the most recently available fiscal year expenditure data from the OMBIL database.

Step 3: Review Historical Inputs – The analysis incorporates best available historical data, and to the extent there is updated or more accurate data available, the user should update as appropriate. As previously mentioned, the user should only update cells that are colored yellow with blue font, as those denote user input cells. All other cells are tied to formulas, altering them without thoroughly studying the model may result in calculation errors or incorrect results.

After the user has updated the aforementioned inputs and conducted a review of the assumptions, the spreadsheet model performs the calculations required to arrive at the capital stock estimates individually for each functional category as well as the total USACE capital stock estimate.

Step 4: Update Input Data on the Business Line Analysis Tab – Obtain the latest business line expenditure data from HQUSACE programs Division.

Only after the user has made the updates to the CCI and expenditure data for the baseline scenario can the *Sensitivity Console* be used.