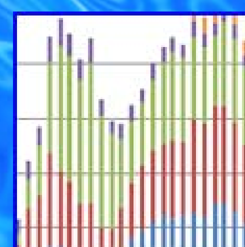
Institute for Water Resources

December 2013

Estimating USACE Capital Stock, 1928 to 2011

2013-R-04



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This report presents updated estimates of the capital stock value of water resources infrastructure built by the U.S. Army Corps of Engineers (USACE) from 1928 to 2011. This infrastructure is substantial, consisting of many different types of capital such as dams, levees, harbors and waterway improvements, locks, channels, hydroelectric generating works, and recreation facilities.

This portfolio of water resources assets provides an annual stream of benefits to the nation in the form of transportation costs savings, flood damages prevented, electric power production, 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 sustain this stock of infrastructure, while the effects of wear and tear, even assuming proper maintenance, subtract from its value. Tracking the total value of USACE capital stock is one way of assessing capability of sustaining services and benefits in the absence of specific, disaggregated, “bottom up data.” This analysis builds on and updates two prior estimates of the value of USACE water resources capital stock.

Estimating USACE Capital Stock, 1928 to 2011

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Mitch Horrie, CDM-Smith

USACE Institute for Water Resources

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USACE Institute for Water Resources

The Institute for Water Resources (IWR) is a U.S. Army Corps of Engineers (USACE) Field Operating Activity located within the Washington DC National Capital Region (NCR), in Alexandria, Virginia and with satellite centers in New Orleans, LA; Davis, CA; Denver, CO; and Pittsburg, PA. IWR was created in 1969 to analyze and anticipate changing water resources management conditions, and to develop planning methods and analytical tools to address economic, social, institutional, and environmental needs in water resources planning and policy. Since its inception, IWR has been a leader in the development of strategies and tools for planning and executing the USACE water resources planning and water management programs.

IWR strives to improve the performance of the USACE water resources program by examining water resources problems and offering practical solutions through a wide variety of technology transfer mechanisms. In addition to hosting and leading USACE participation in national forums, these include the production of white papers, reports, workshops, training courses, guidance and manuals of practice; the development of new planning, socio-economic, and risk-based decision-support methodologies, improved hydrologic engineering methods and software tools; and the management of national waterborne commerce statistics and other Civil Works information systems. IWR serves as the USACE expertise center for integrated water resources planning and management; hydrologic engineering; collaborative planning and environmental conflict resolution; and waterborne commerce data and marine transportation systems.

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Other enterprise centers at the Institute's NCR office include the International Center for Integrated Water Resources Management (ICIWaRM), under the auspices of UNESCO, which is a distributed, intergovernmental center established in partnership with various Universities and non-Government organizations; and the Conflict Resolution and Public Participation Center of Expertise, which includes a focus on both the processes associated with conflict resolution and the integration of public participation techniques with decision support and technical modeling. The Institute plays a prominent role within a number of the USACE technical Communities of Practice (CoP), including the Economics CoP. The Corps Chief Economist is resident at the Institute, along with a critical mass of economists, sociologists and geographers specializing in water and natural resources investment decision support analysis and multi-criteria tradeoff techniques.

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Acknowledgements

The following document contains materials from CDM Smith that were delivered to IWR in partial fulfillment of Contract # W912HQ-10-D-004. CDM Smith's Mark Dunning, Mitch Horrie with technical advice from Barbara Fraumeni, were the authors. IWR's Wen-Huei Chang, David Moser, Robert Pietrowsky, Erin Rooks, and Norman Starler were significant contributors. The authors and contributors are deeply indebted to the reviewers listed on page 64 from IWR, USACE Army (Civil Works), Bureau of Economic Analysis (BEA), and Bureau of Labor Statistics (BLS), but they are responsible for any remaining errors.

Executive Summary

This report presents updated estimates of the capital stock value[1] of water resources infrastructure built by the U.S. Army Corps of Engineers (USACE) from 1928 to 2011. This infrastructure includes many different types of capital such as dams, levees, harbors and waterway improvements, locks, channels, hydroelectric generating works, and recreation facilities, but excludes restored ecosystem habitat. This portfolio of water resources assets provides an annual stream of benefits to the nation in the form of transportation costs savings, flood damages prevented, electric power production, and recreation, that contribute to national economic prosperity, global competitiveness, and the health, safety, and quality of life of our citizens. Each year Federal investments sustain this stock of infrastructure, while the effects of wear and tear, even assuming proper maintenance, subtract from its value. Tracking the total value of USACE capital stock is one way of assessing capability of sustaining services and benefits in the absence of specific, disaggregated, "bottom up data."

This analysis builds on and updates two prior estimates of the value of USACE water resources capital stock. The first study was performed as part of the Federal Infrastructure Strategy Program in the early 1990's (USACE, 1994c) and estimated the value of USACE water resources capital stock for the years 1936 through 1992. The second study was performed in 2003 and it updated estimates of USACE water resources capital stock through 1999 (USACE, 2003). The current study follows the basic approach of the two earlier studies and estimates the value of USACE water resources capital stock using the same Perpetual Inventory Method (PIM). This method has been endorsed by the Organization of Economic Cooperation and Development (OECD) as the preferred approach for estimating capital stock. The OECD is the internationally accepted authority on capital measures.

This study makes four notable advancements from prior studies.

- This study increases the asset retirement age from 50 years to 60 years for the Flood Risk Management, Multipurpose, and Mississippi River and Tributaries (MR&T) functional categories and to 75 years for the Navigation functional category. The two previous studies assumed the average retirement age of all USACE civil works capital assets to be 50 years. There are two reasons for this retirement age increase: (a). Using data from the Chief of Engineers Annual Report, the current average age of USACE projects was computed and discovered to be greater than 50 years for each of the functional categories. (b). An analysis of U.S. Bureau of Economic Analysis (BEA) data also supports these increases.

- The current study includes dredging as a special case of the investment that sustains the capital stock value of navigation channels. Prior studies did not account for the effect of dredging.

- The current study uses available major rehabilitation data to account for the impact of these expenditures on increasing the value of capital stock value over time. Prior studies did not account for the impact of major rehabilitation investments to sustain capital stock.

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[1] Key Terms and concepts used in this paper are defined in the glossary found in Appendix A of this report. They are identified by bolded text in the body of this paper.

- Monte Carlo simulation is employed to evaluate assumption sensitivities, recognizing a substantial amount of uncertainty remains in measuring productive capacity of capital stock, principally due to data limitations.

The PIM model implemented for this analysis uses the time series of USACE Civil Works water resources investments in five functional categories: Navigation, Flood Risk Management, Multipurpose, Mississippi River and Tributaries (MR&T), and Dredging shown in **Figure ES-1**.

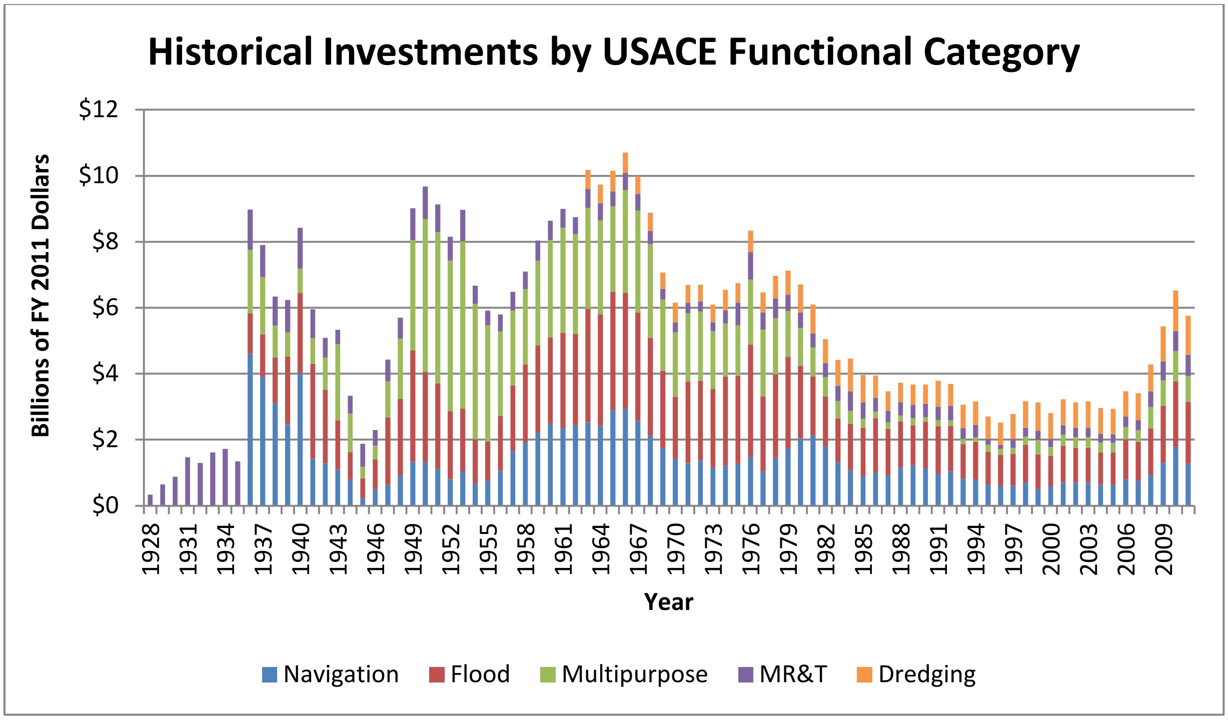

Figure ES-1
Historical USACE Investments by Functional Category 1928 to 2011

As the figure illustrates, total investments in the functional categories varied each year. Reliable 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 1980, including the dip in funding during World War II (1941 to 1946), the average annual USACE Civil Works water resources capital investment was $6.7 billion in 2011 dollars. Using the PIM, the cumulative effect of these investments is shown in **Figure ES-2** below, with investments over time contributing to the growth in USACE capital stock value.

This study finds capital stock value increased at an average of $5.35 billion per year from 1936 to its peak of $264.4 billion in 1982.[2] At this point, the pattern of appreciation in capital stock shifted to a pattern of decline, and USACE capital stock value lost just over $2.4 billion annually between 1982 and 2011. Currently (2011), the value of USACE capital stock is estimated at $191.4 billion, representing a decline of nearly 27 percent from its peak value in 1982. This also represents the shift from investing in massive, multipurpose projects to smaller, single purpose projects. The total capital value (summation of the five functional categories) is shown in **Figure ES-3** below.

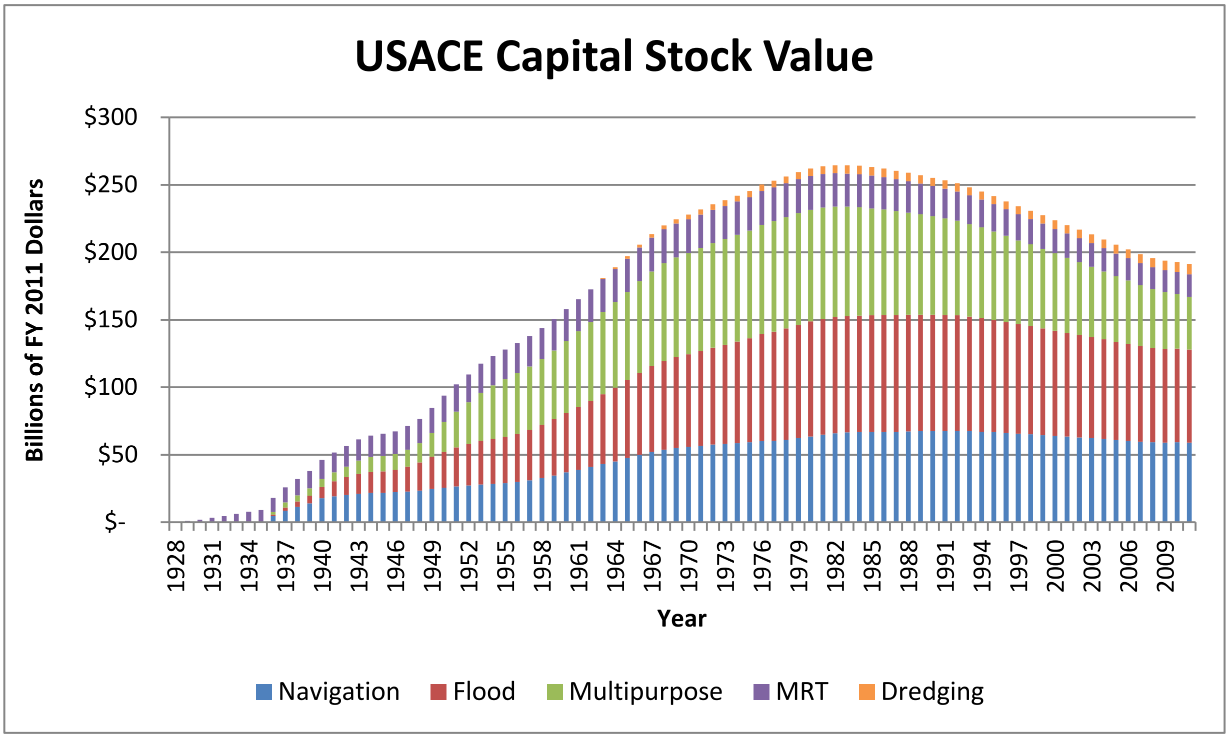

Figure ES-2

USACE Capital Stock Value by Functional Category 1928 to 2011

[2] All dollar values are expressed in 2011 dollars.

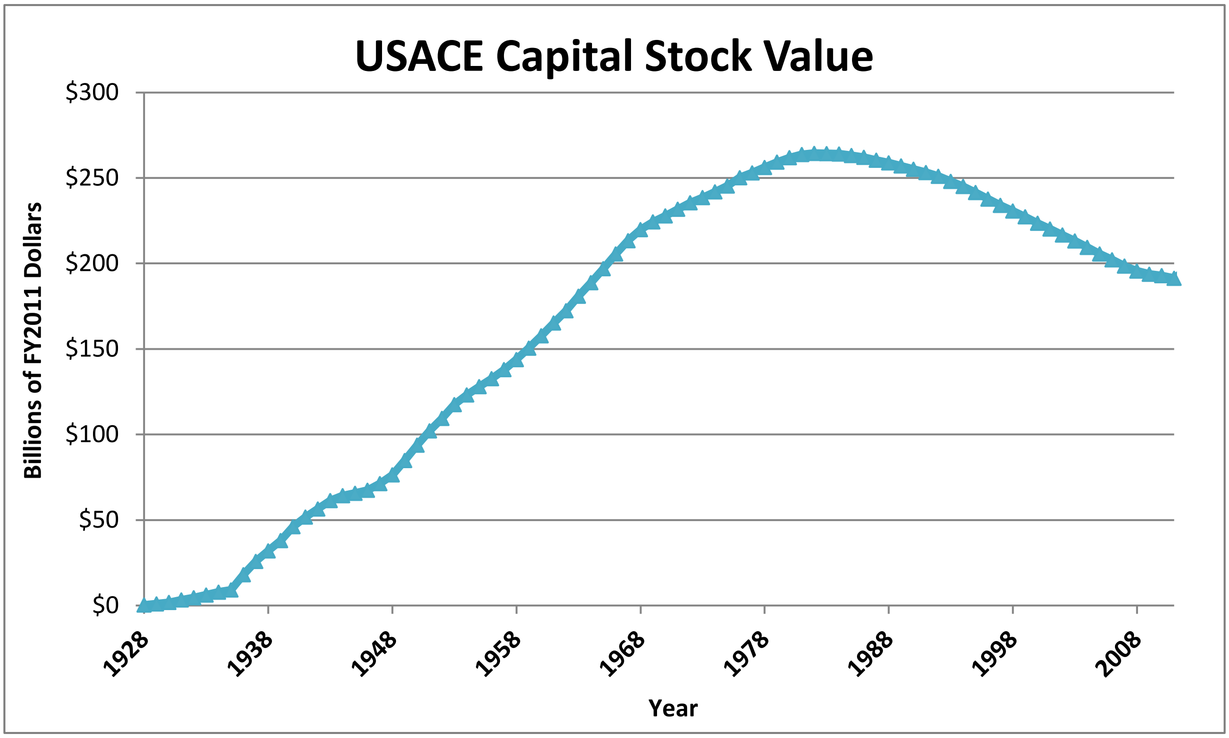

Figure ES-3
USACE Capital Stock Value, 1928 to 2011

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

This analysis of the USACE capital stock suggests that the USACE capital stock value has been in a period of decline since the early 1980's and that new investments have not compensated for asset retirements and deterioration. Since the early 1980's the value of this infrastructure has declined by nearly 30 percent. The implication of this finding is that an aging infrastructure with lower productive efficiency will ultimately affect USACE's ability to provide important benefits to the Nation. (U.S. Army Corps of Engineers Civil Works Program Five-Year Development Plans for FY10-FY14 and FY 11-15 report performance declines for several business programs dependent on capital stock including inland navigation, deep draft navigation, and hydropower production.)

- The USACE capital stock value increased $4.9 billion on average each year from 1928 to 1982, representing a 13.1 percent average annual increase. From 1982 to 2011 the USACE capital stock value decreased by an average of $2.5 billion each year (1.1 percent annually). For 2011, USACE capital stock is estimated as being $191.4 billion or approximately what it was between 1964 and 1965.

- If the average annual rate of decline in USACE capital stock value observed from 1982 through 2011 persists, USACE capital stock will have lost approximately half its peak value by the year 2044, see **Figure ES-4**.

- Under the current study assumptions, over the next ten years $6.9 billion in annual investment would be required to sustain the capital stock value near its current level (see Figure ES-4). Anything less will result in further decline over that time frame. To compare, the Construction

General account appropriations for fiscal years 2009, 2010, and 2011 were $2.1 billion, $2.0 billion, and $1.6 billion respectively. These appropriations include spending for major rehabilitation.

- An analysis of the impact of dredging on the USACE capital stock value shows that USACE investments in dredging have remained relatively steady for the past 50 years. Given this pattern of investment, as well as the assumptions of service life and the deterioration pattern, the dredging capital stock value is currently at its greatest level and, at present, accounts for approximately 4 percent of the total USACE capital stock value.
- Accounting for major rehabilitation spending in the capital stock analysis contributes to the 2011 total USACE capital stock value by about $10.3 billion (5.7 percent).

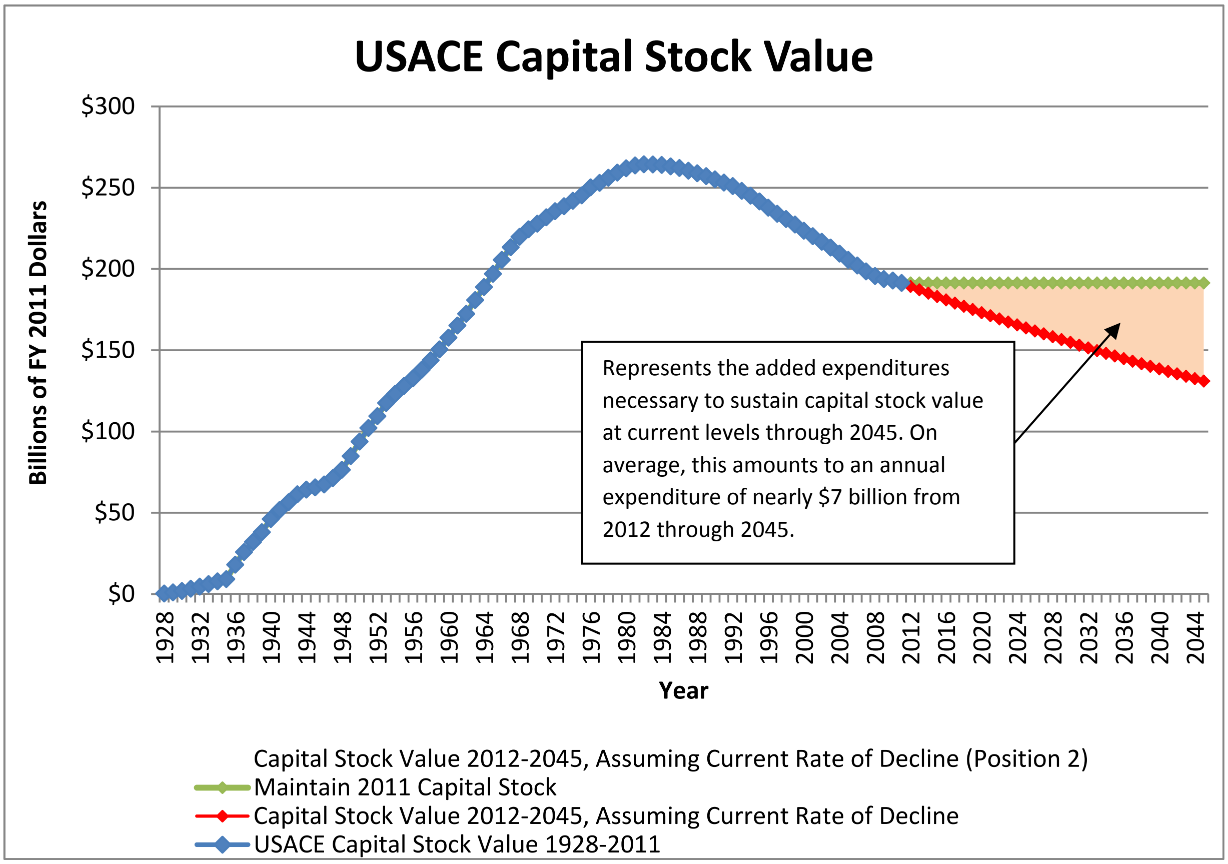

Figure ES-4

USACE Capital Stock Value, 1928 to 2045: Continuation of 1982-2011 Decline versus Sustainment of 2011 Capital Stock Value

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Section 1

Introduction

1.1 Background

The U.S. Army Corps of Engineers' (USACE) portfolio of Civil Works water resources infrastructure projects[3] 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 includes approximately 11,750 miles of levee systems, 692 dams, 926 shallow and deep-draft harbors, 207 lock chambers at 171 sites, and 75 hydroelectric facilities with 353 generating units among other ***assets***. USACE infrastructure also provides reservoir storage for water for municipal, industrial, and agricultural purposes and manages 422 recreation projects in 43 states. In addition, USACE is involved in environmental mitigation and restoration of the natural functions of ecosystems.

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 ***investments*** 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 damage reduction, hydropower availability as a substitute for energy alternatives, recreational opportunities, and water supply for municipal and industrial, and agricultural activities. These benefits contribute to our Nation's safety, quality of life, and economic competitiveness. For instance, America has saved over $7 in flood damages prevented for every $1 invested in USACE dams and levees between 1928 and 2010 (House 2012, 8), USACE hydropower plants generate 24 percent of the Nation's hydropower capacity and 3 percent of total electric capability (USACE, 2012c), and over 95 percent of the Nation's overseas trade, by weight, and over 75 percent, by value, move through USACE ports by ship each year (USACE, 2012d).

Information about USACE water resources capital stock and its potential to sustain benefits is very important to provide to the Administration, to Congress, and to the American public. As described more fully below, this current study updates the estimated value of USACE water resources capital stock and estimates the investment needed to restore the capital stock to its peak value. This capital stock study complements an update of the national monetary benefits produced by this USACE water resources infrastructure (See USACE, 2012a). These monetary benefits can be considered to be the "return on investment."

Moreover, this capital stock study provides national context, but is just one of several indicators that should be considered in making future, project specific investments and operation and maintenance decisions. Such indicators include measurement of benefits currently being produced, the potential for generating future benefits, physical infrastructure condition, public safety and costs.

[3] 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.

1.2 Purpose and Objectives

The purpose of this study is to update the estimate of the value of the USACE water resources capital stock for the years 1928 to 2011. Specific objectives of the study include:

- Briefly review prior studies estimating USACE water resources capital stock.
- Describe and apply the ***Perpetual Inventory Method (PIM)*** to estimate the value of USACE water resources capital stock.
- Relate the findings of the study to the conclusions reached in a companion study[4] that updates the estimation of the monetary benefits to the Nation produced by USACE Civil Works water resources infrastructure.
- 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 the PIM 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 in the accompanying Microsoft Excel workbook using the PIM. Appendix C of this report provides an abbreviated illustration of the capital stock calculation.
- **Section 4**: Sensitivity Analysis - conducts a sensitivity analysis of key assumptions used in the capital stock estimate.
- **Section 5**: Findings and Conclusions - presents findings of the 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 estimating benefits produced by the capital stock. Finally, the section also identifies opportunities to advance capital stock analysis in the future.
- **Section 6**: References

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.

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[4] See Estimating Benefits to the Nation Produced by the USACE Civil Works Program: Estimates of National Economic Development Benefits and Returns to the Treasury for 2010 (USACE, 2012a). This report updates estimates of monetary benefits produced by Corps water resources infrastructure for the year 2010. 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.

Appendix B: Review Meeting Summary - This appendix presents a summary of comments provided in a review meeting held at the Institute for Water Resources to discuss the work presented in this report.

Appendix C: Example Calculation Spreadsheet – 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 five 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 in order to simplify the example.

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Section 2

Methodology

This section introduces key elements and concepts of the PIM and provides a stepwise discussion of the methodology used 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 PIM.

2.1 Prior Studies Estimating USACE Capital Stock Value

This report builds upon two previous studies performed in the last 20 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 (FISP) (USACE, 1994c). This study utilized a state-by-state time-series of annual USACE ***expenditures*** in four ***functional categories***: Navigation; Flood Control; Multiple Purpose; and Mississippi River and Tributaries (MR&T) from 1936 through 1992. Capital stocks were estimated based on these investment flows using the PIM. The authors of this 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*** (the latest year reported in the report tables), in 2011 dollars, estimated by this study was $123.3 billion using the straight-line asset decay pattern and about $200 billion using the economic asset decay pattern.

The second effort to quantify USACE capital stock value was performed in 2003 (USACE, 2003) to estimate the value of the capital stock through 1999. This study also utilized the PIM in estimating USACE capital stock 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 pattern*** with a ***Beta (β) Factor*** of 0.9 were assumed for all functional categories.[5] The current study used these assumptions to estimate a 2011 capital stock value of $172 billion. Expert review of the 2003 Study recommended that a geometric pattern of asset decay be applied to the USACE capital stock estimate. The current study applied this geometric pattern to estimate a 2011 value of $189 billion. See Section 5 of this study. The current study also uses the PIM and historical USACE Construction General (CG) appropriation accounts for the new work investment flows to build upon the previous USACE capital stock studies and update the estimate to a 2011 value. Assumptions for service life and pattern of asset decay have been modified and expenditures for dredging and major ***rehabilitation*** have been incorporated into the estimate. As will be detailed below, the current study also assumes a hyperbolic age-efficiency pattern; however, the beta factor is assumed to be 0.6 for the Flood Risk Management, Multipurpose, and MR&T functional categories rather than 0.9 (as used in previous studies). For this study, the Navigation functional category beta factor is assumed at 0.5. Additionally, the current study assumes a 60-year service life for the Flood Risk Management, Multipurpose, and MR&T functional categories as opposed to the 50-year service life assumed for the previous study. For this study, the Navigation functional category service life is assumed at 75 years. The overall pattern of asset ***deterioration*** remains the same (i.e., an increasing rate of deterioration

5 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. Furthermore, for additional detail, please see OECD, 2009.

over time), however a smaller beta factor and longer average asset life works to prolong asset life in comparison to a larger beta factor and shorter average asset life.

2.2 Perpetual Inventory Method

The PIM is the method preferred by the ***Organization of Economic Cooperation and Development***[6] ***(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 from a stream of current and past investments (Hulten, 1990). With the exception of Korea, Japan, and the Netherlands[7], which have performed surveys of capital stock involving site visits by enumerators, all other OECD countries utilize the PIM for their capital stock estimates (Blades, 2001). The 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 infrastructure cannot be readily or economically evaluated. In these circumstances the 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.

The 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[8]).[9] Retirements and deterioration are further explained as follows:

- 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 ***mortality 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 are described in the following section.

2.3 Assumptions

This section provides a discussion of the PIM components and assumptions used for this analysis. See the glossary in Appendix A of this report for definitions of technical terms presented in this section.

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

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

[8] 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 percent of their productive capacity in perpetuity and some level of diminished productive capacity is realized over time.

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

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 β function.

2.3.1 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 Management, and Multiple Purpose 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:

1. **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 locks and dams, and improved channels.

2. **Flood Risk Management** – A primary missions 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 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 renourished beaches (a small percentage of total flood risk management investments).

3. **Multiple Purpose** – Some USACE Civil Works water resources infrastructure provides benefits related to more than one project purpose. For instance, a hydropower dam and reservoir provides electricity generation as well as water supply storage. Therefore, this dam is an example of an infrastructure item serving two purposes. For the purposes of this study CG investments supporting more than one purpose are classified under the Multiple Purpose functional category.

[10] The Mississippi River and Tributaries (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.

4. **Mississippi River and Tributaries (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 analysis do not originate from the USACE Civil Works CG appropriation account. Rather, within the MR&T appropriation account, appropriations are allocated to a 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.

5. **Dredging** – USACE conducts periodic dredging of inland and coastal waterways in order 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, therefore, 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. Additional details regarding the assumptions applied to the PIM for the Dredging functional category are presented in Section 2.4.6.

Cumulative investments in new work for the functional categories of Navigation, Flood Risk Management, and Multiple Purpose are for the years 1936 through 2011. For MR&T, cumulative investments span the years 1928 through 2011. For Dredging, cumulative investments span the years 1963 through 2011 (years for which credible data are available).

2.3.2 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 in order to justify capital expenditures for these projects. The investments in major rehabilitation serve to restore infrastructure performance, in essence extending their service lives such that the infrastructure is restored to an improved level of service.

Prior to 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 Construction General account (USACE, 2011b). Therefore it is understood that the available USACE expenditure data used to calculate capital stock value does not account for major rehabilitations expenditures before FY 1993. Consequently, additional data identifying major rehabilitation expenditures prior to calendar year 1994 was sought in order to account for these expenditures' contribution to the capital stock value over time.

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 2011.

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.

2.3.3 Retirement Profile

The retirement age of a single asset is the age at which it is removed from service, representing the end of its productive life. A retirement profile models the process of removal of a group of assets. This study makes the assumption that assets operate until the end of their service lives and are thereafter immediately retired from service, or else that substantial new capital is expended and the asset is "renewed." At this point the service life of the asset is effectively restarted. New capital expended on old assets during its service life is often referred to as *rehabilitation* or a ***recapitalization***.

Service Life

The service life assumption for a portfolio of assets refers to the age at which all of the assets in the portfolio are assumed to retire. For the purposes of this study, and under the framework of the PIM model which requires a single asset retirement age for each USACE functional category, the service life is the assumed age at which assets will retire from the USACE capital stock portfolio. The service life assumption takes into account all the factors that would cause an asset to be retired from the capital stock portfolio. These include:

- Normal wear and tear that exhausts the productive capacity of the 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, and
- 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 assets within a particular functional category are removed from service at their assumed service life age. Therefore, while the above bulleted items are factors that could contribute to the retirement of a single asset within the capital stock portfolio, the service life assumptions collectively consider the retirement characteristics of all the assets within a given functional category within the portfolio. USACE asset inventory data that would allow for the computation of the ***survival function*** and, subsequently, the ***mean service life*** of individual asset types (e.g., dams, powerhouses, levees, dikes, and lock chambers), was not available for this analysis.[11] Therefore, the service life assumption for each functional category 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 caveats noted in the literature regarding the difficulties in determining the service life of capital stock, assumptions made for this analysis are recognized to involve considerable uncertainty.

Table 1 presents a simple tabulation of 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. The ages reported in Table 1 were verified by additional tabulations performed by the Navigation Data Center (USACE Navigation Data Center, 2012).

This report classifies projects under the categories of Navigation, Flood Control, and Multiple Purpose. [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 a direct analogy to average service life because assets that have been retired or otherwise removed from service are not represented in the estimate. 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

Functional Category	Number of Projects	Average Age	Standard Deviation
Flood Control Reservoirs (Operable)	333	50.95	17.48
Navigation Locks and Dams USACE Owned or Operated	257	63.87	30.64
Multiple Purpose, including Power	74	51.32	16.86
Flood Control Reservoirs (Operable)	333	50.95	17.48

[11] Survival function and mean service life are common concepts discussed in PIM literature. A survival function depicts the pattern of asset retirements for a group of assets over time, allowing for the computation of the mean service life of that group of assets. See the glossary in Appendix A for definitions of these terms and OECD, 2009 for further detail.

[12] For example, in the 1940s and 50s the Internal Revenue Service's Bulletin F provided useful life estimates for over 5,000 assets and provided methods for computing their depreciation rates (IRS, 2012).

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

Prior USACE capital stock estimates used a 50-year service life assumption for all functional categories (USACE, 1994c and USACE, 2003). The 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 1999 report *Fixed Reproducible Tangible Wealth in the United States, 1925-94*. In this report, the BEA shows service life assumptions for government infrastructure as follows in **Table 2**:

Table 2: Bureau of Economic Analysis Service Life Estimate for Government Nonresidential Structures

Asset	Service Life (years)
Buildings:	
Industrial	32
Educational	50
Hospital	50
Other	50
Nonbuildings:	
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 "Nonbuildings" generally use an asset service life of 60 years. These categories of infrastructure approximate the kind of large infrastructure that projects represented by USACE water resources infrastructure projects, and 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 compared to the other functional categories. These tabulations and those performed by the USACE Navigation Data Center provide further confirmation that Navigation projects are generally older than projects in other functional categories with a mode age of 75 years compared to 45 years for dams and 55 years for hydropower plants (USACE Navigation Data Center, 2012). Therefore, this study uses 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. Further explanation of the 75 year Navigation service life assumption is provided in Section 3.2.1 of this report.

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 2.4.6 below a separate, shorter assumption for service life is applied to the Dredging functional category.

Mortality Function

The mortality function is used in conjunction with the service life assumption to define the retirement profile of expenditures made to the capital stock. This study uses the ***simultaneous exit mortality function*** assumption, which is consistent with past USACE studies and most capital stock analyses of civil works. Simultaneous exit refers to a pattern of retirement whereby all expenditures of a particular vintage (i.e., common year of capital expenditure) are retired from the capital stock when they reach the service life assumption (e.g., 60 years). The simultaneous exit assumption is illustrated below in **Figure 1**.

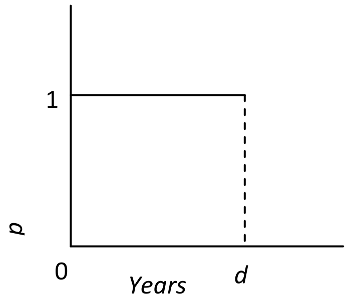

Figure 1
Simultaneous Exit Mortality Function

Additional discussion of the simultaneous exit retirement profile can be found in later in this section as well as in the OECD Manual 2009.

Where:
d = service life
p = percent of assets in service

Issues related to the simultaneous exit simplifying assumption are partly addressed through the use of a ***Monte Carlo simulation***. The Monte Carlo simulation performs multiple iterations of the analysis varying the service life assumption to produce a probability distribution to the final USACE capital stock calculation. This approach is employed to provide greater confidence in the findings of this report.

Retirement Profile Summary

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

1. All capital assets in the USACE Civil Works capital stock portfolio are assumed to retire when they reach their service life assumption. This is a simplifying assumption that does not reflect actual historical USACE asset retirement patterns and is required due to lack of sufficient empirical USACE asset retirement data.

2. A simultaneous exit mortality function is assumed within the PIM model. The mortality function refers to the manner which assets are retired relative to their age. Using the aforementioned service life assumptions, the simultaneous exit mortality function operates within the PIM model such that an asset is retired when it reaches its assumed service life.

These assumptions work together to form the retirement profile of USACE Civil Works assets 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.

2.3.4 Estimated Deterioration

Age-Efficiency Profile

The age-efficiency profile describes the time pattern deterioration in productive efficiency of a capital stock (OECD, 2009). Productive efficiency refers to an asset’s ability to perform at its originally intended level of service. Typically, the age-efficiency profile is expressed in relation to the productive efficiency of a new asset (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 asset, its productive efficiency will degrade due to wear and tear, requiring periodic maintenance and capital renewal. The age-efficiency function used for an asset is calculated to approximate the time series of investments necessary to keep the asset operating to its originally-constructed standard.

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: hyperbolic, linear, geometric, and One-Hoss Shay.[14]

Based on simple asset observations and the premise behind the 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. The hyperbolic function is a general function that could be used to produce a wide variety of mortality distributions. The assumption used for this study defines a particular hyperbolic function to model USACE capital stock deterioration (see the following section for more detail regarding the hyperbolic function as a pattern of asset deterioration).

Together with the service life assumption and the simultaneous exit mortality function 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 of its assumed service life age, at which point the asset is retired, regardless of the level of efficiency it possesses. 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.

Hyperbolic Function

Hyperbolic functions can be used to approximate a wide variety of age-efficiency patterns and those with a ***beta factor* (*β*)** greater than zero are concave in shape (See **Figure 2**).[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 towards the end of their service lives. For this study, β is assumed to be 0.6 for the Flood Risk Management, Multiple Purpose, 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 value for the Navigation functional category is assumed to be 0.5, the range minimum, due to its unique life-cycle characteristics.

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

[15] The beta (β) factor represents the percentage change in the level of service when age moves by one unit, holding characteristics and time constant. See the OECD Manual 2009 for additional information regarding the application of the β factor in the PIM.

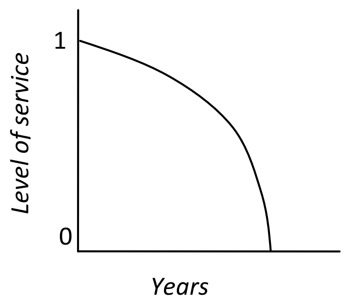

Figure 2
Concave Hyperbolic Age-Efficiency Profile

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 3**). Using this function, loss of productive capacity is calculated as $1/N$ where N represents the asset's service life.

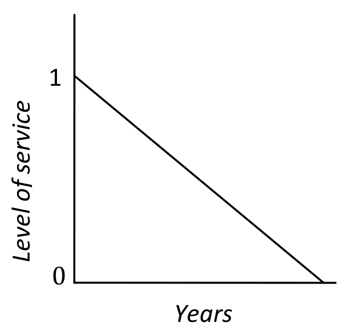

Figure 3
Straight-line Age-Efficiency Profile

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 because productive capacity is greater at this time (see **Figure 4**). This pattern is generally opposite of the concave hyperbolic patterns which exhibits a slow deterioration at the beginning of the service life and rapid deterioration at the end of the service life.

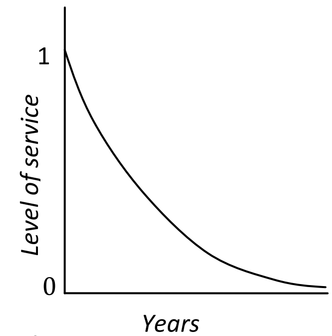

Figure 4
Geometric Age-Efficiency Profile

One-Hoss Shay Function

The One-Hoss Shay age-efficiency profile represents a pattern whereby assets maintain their full productive efficiency 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 efficiency 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 5**. As the figure shows, the One-Hoss Shay age-efficiency profile also exhibits a simultaneous exit mortality function.

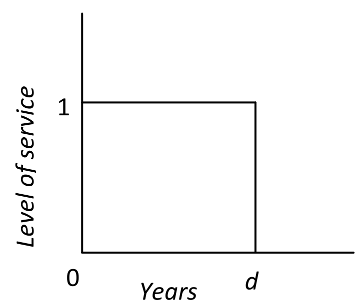

Figure 5
One-Hoss Shay Age-Efficiency Profile

2.4 Other Considerations

2.4.1 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 must adjust all dollar figures to a baseline point in time and adjust for inflation. ***Nominal dollars*** on the other hand do not adjust values for inflation. By convention, this report will express all monetary figures in constant dollars using 2011 as the base year. The Engineering News-Record Construction Cost Indexes (ENR, 2011) is used to adjust dollar values to constant 2011 dollars.

2.4.2 Beginning Date for the Calculation

A critical consideration in the PIM is the beginning date of the calculation and the corresponding capital stock value at this point in time. Calculations performed in the 1994 capital stock analysis made the assumption this value was zero starting in 1928. Problems with this assumption are noted in the 2003 USACE report.[16] In that report, the authors recommend that the 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 is 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 in the base year.

2.4.3 Financial Data Considerations

There are a number of specific considerations related to the use of available financial data. This is generally related to differences in accounting methodologies used during different time periods.[17] Therefore, special care must be given to ensure consistent definitions and practices were used throughout the period of analysis. A detailed review of financial data used was beyond the scope of this report and data provided by USACE were used at face value. This remains an area introducing some uncertainties to the calculations. Section 5.3 of this report provides further discussion of data limitations encountered for this update.

2.4.4 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:

- The aggregation of expenditures into functional areas (i.e., the five functional categories introduced in Section 2.1 of this report) fundamentally limits the descriptive quality of the analysis (pg. 41).
- The aggregate nature of the USACE investment data required that the asset life assumption be applied uniformly across all functional areas (pg. 32), with the exception of the Dredging functional area which is treated as a special case for the purposes of this study.
- The aggregated nature of the USACE investment data used prevented further categorization and analysis beyond the split of expenditures into the five functional areas (pg. 38).

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 ameliorated with data that allows for finer disaggregation of inventory subsets and investments.

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[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 construction general account.

2.4.5 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 referring to the decrease in the value of assets. By contrast, deterioration is focused on performance rather than value such that when an asset deteriorates, performance is negatively affected.

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 a representative function that will be limited to the hyperbolic form with a concave shape.

2.4.6 The Case of Dredging Infrastructure

Dredging represents a special case when it comes to capital stock valuation and the PIM. Generally, capital stock flows fit neatly into the category of manmade structures and infrastructure. 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 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 a manmade structure aging. Resetting the productive capacity of a manmade structure at the end of its service life is by definition 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 to it.

Due to natural processes which 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 3) 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 depreciation 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 one percent on average over the first 15 years of useful life and never more than 4 percent in any year. Comparably, in the dredging analysis, assets decline at 6.25 percent 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.

3.1 Investment Data

The USACE Headquarters Programs Division maintains a database of historical investments in Civil Works projects organized by the functional categories; Navigation, Flood Risk Management, Multiple Purpose, MR&T, and Dredging. These data were provided by USACE for years 1928 through 2007 in a Microsoft Excel workbook. Beginning in 2008, data from the USACE OMBIL (Operations and Maintenance Business Information Link) were used to track spending allocations. These data were obtained from USACE and entered into the Microsoft Excel workbook consistent with past practices.

The OMBIL database is organized as a cost matrix with seven main funding sources. Within each funding source, funds are allocated across nine separate business lines. Within each business line, funds are then allocated among operations, maintenance, and “unknown" investments.

The seven funding sources are as follows:

1. Baseline (within the Baseline funding category there are five subcategories where funds are appropriated):
    a. Operations &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. IWTF (Inland Waterway Trust Fund)
4. In Kind Services
5. PMA - Power Marketing Agencies
6. Recovery - American Recovery and Reinvestment (ARRA) funds
7. Supplemental - Supplemental appropriations

The nine business lines are:

1. Emergency Management
2. Environment
3. Flood Risk Management
4. Hydropower
5. Navigation
6. Recreation
7. Regulatory
8. Unknown
9. Water Supply

"Unknown" investments account for approximately 70 percent of the total annual appropriations from FY 2008 through FY 2011. In keeping with previous analyses, all unknown costs are assumed to be investments in productive capital and in this study were proportionally allocated across the OMBIL business lines using a 25 year average allocation pattern (i.e., the unknown investments that began in 2008 were dispersed among OMBIL business lines according to the 25 year average of the proportion of investments allocated to the respective business lines).

OMBIL investment data and associated calculations are available in the accompanying PIM model spreadsheet. This study only used data from six of the nine OMBIL business lines that are directly related to USACE Civil Works water resource investments; Emergency Management, Environment (including restored ecosystem habitat), and Regulatory were excluded from the calculation. **Figure 6** shows the combined annual investments for the Navigation, Flood Risk Management, Multiple Purpose, MR&T, and Dredging functional categories from 1928 to 2011. These investments include major rehabilitation spending from 1936 through 2011. It should be noted that the 2008 to 2011 increase in USACE capital stock investments shown in Figure 6 is largely attributable to funds provided by the American Recovery and Reinvestment Act of 2009 (ARRA) and listed under the Unknown investment account in the OMBIL database.

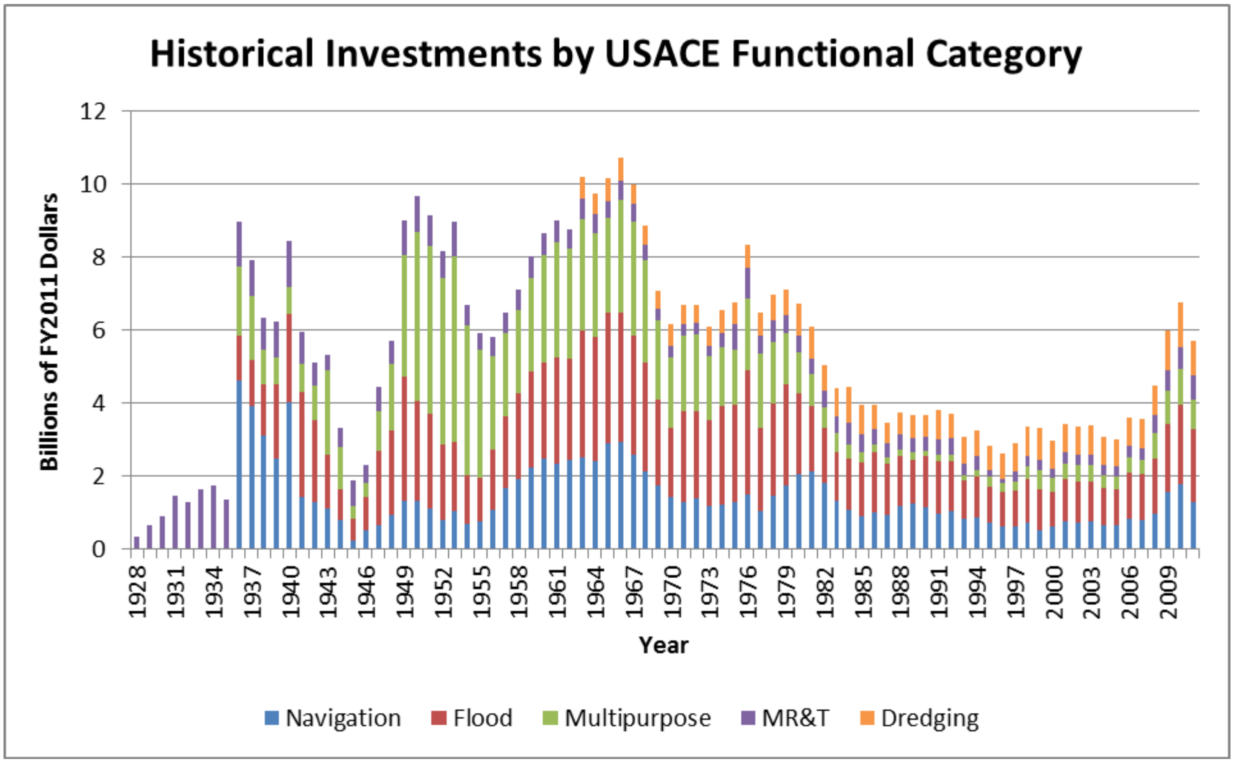

Figure 6
Historical Investment in USACE Civil Works Water Resource Infrastructure by the Five Functional Categories

3.2 Capital Stock Calculations

Following the OECD procedure identified in section 2.1, 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, Multiple Purpose, MR&T, and Dredging) is provided below. In summary, these categories include all the Civil Works projects funded through USACE Civil Works Program appropriations, representing the entire capital stock inventory built.

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 with the exception of 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 (β) of 0.6 to describe the pattern of asset deterioration (age-efficiency profile) for all functional categories with the exception of 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 Multiple Purpose, and 1963 for the Dredging functional category. Data was not available to determine the extent, age, or value of any pre-

existing capital stock portfolios for any of the five functional categories and, 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 the PIM to the time series of investments provided by USACE.

3.2.1 Navigation

Inventory Characterization

USACE maintains 12,000 miles of inland and intracoastal waterways with 207 lock chambers at 171 sites. In addition, USACE manages 926 costal, Great Lakes, and inland channels and harbors. With the exception of 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. For example in 2009, 2.21 billion tons of goods, valued at $1.16 trillion, were handled by U.S. ports and waterways for foreign inbound, foreign outbound, and domestic commerce (USACE, 2010). 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 capita stock estimates presented are based upon a 75 year service life and a hyperbolic beta function of 0.5. Descriptive statistics of existing Navigation projects' age showed that the mean was 56.7 years and the mode was 75 years, indicating that a large portion of existing assets have already reached 75 years of age and are still generating services (USACE Navigation Data Center, 2012). 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. This beta function is justified based upon the observation that a substantial portion of the older USACE navigation infrastructure is approaching obsolescence. For example, many older lock chambers are 600 feet long. However, typical tows are now 1200 feet long. Consequently, these tows must be broken up when passing through the 600 foot lock chambers, requiring additional transportation time and costs. This observed approach toward obsolescence points to the need to model a faster relative decline in the productive capacity of navigation infrastructure compared with other functional categories.

Capital Stock Calculation

The Navigation capital stock calculation is performed in the accompanying Microsoft Excel workbook. **Figure 7** shows the computed capital stock value for this functional category since 1936.

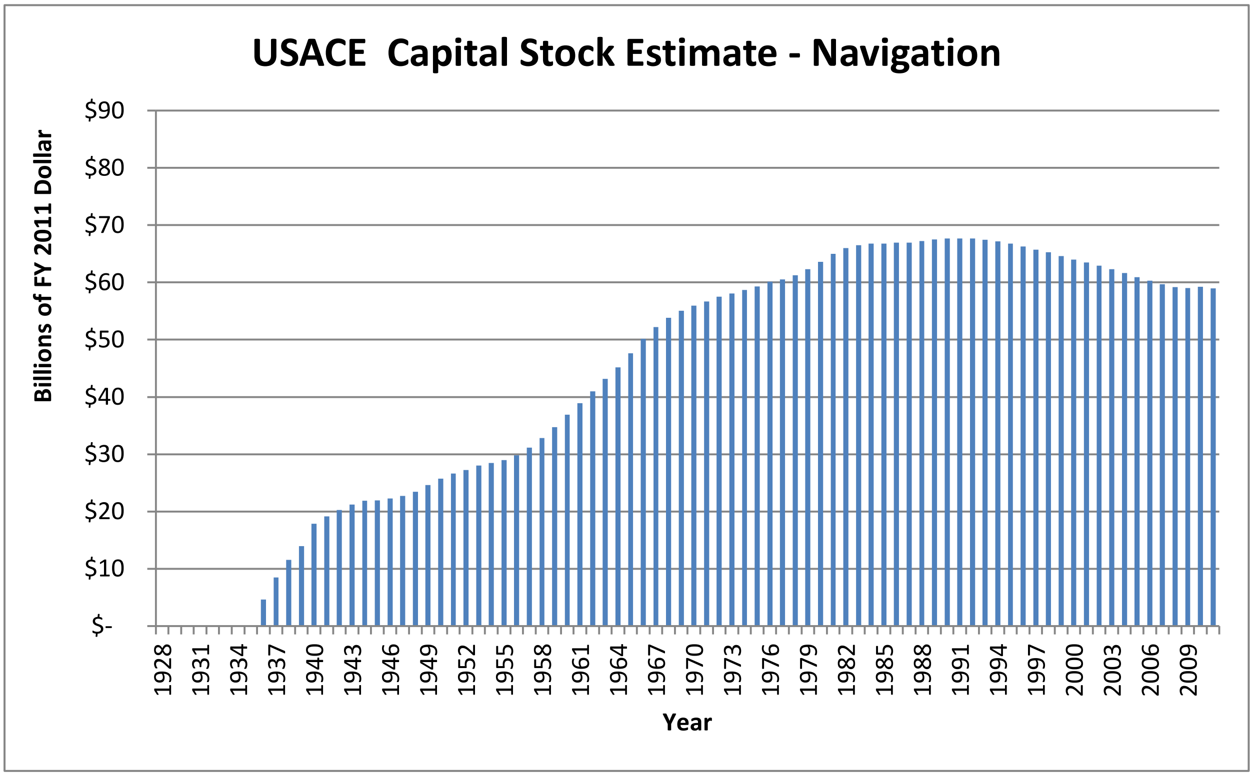

Figure 7
USACE Capital Stock Estimates for the Navigation Functional Category in Billions of 2011 Dollars

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 when investments declined significantly for several years. The post-WWII rate of investments made in this stock starting remained relatively consistent through 1983, increasing at an average rate of 2.0 percent per year (in 2011 dollars).
- The value peaks in 1992 at $67.7 billion. A small uptick beginning in recent years was due largely to recovery from post 9/11 investments in harbors, storm/hurricane recovery supplemental funding, and, more recently, stimulus funding.
- The 2011 USACE Navigation capital stock value is $58.9 billion, or approximately what it was in 1975.
- The average rate of decline from 1992 to 2011 was 0.72 percent per year.

3.2.2 Flood Risk Management

Inventory Characterization

USACE owns and operates 692 dams located throughout the U.S. In addition, USACE built or controls 11,750 miles of levees. 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 in flood-related damages (House 2012, 8).

Capital Stock Calculation

The calculation pertaining to the Flood Risk Management functional category is performed in the accompanying Microsoft Excel workbook. The chart of the final calculation is provided in **Figure 8**.

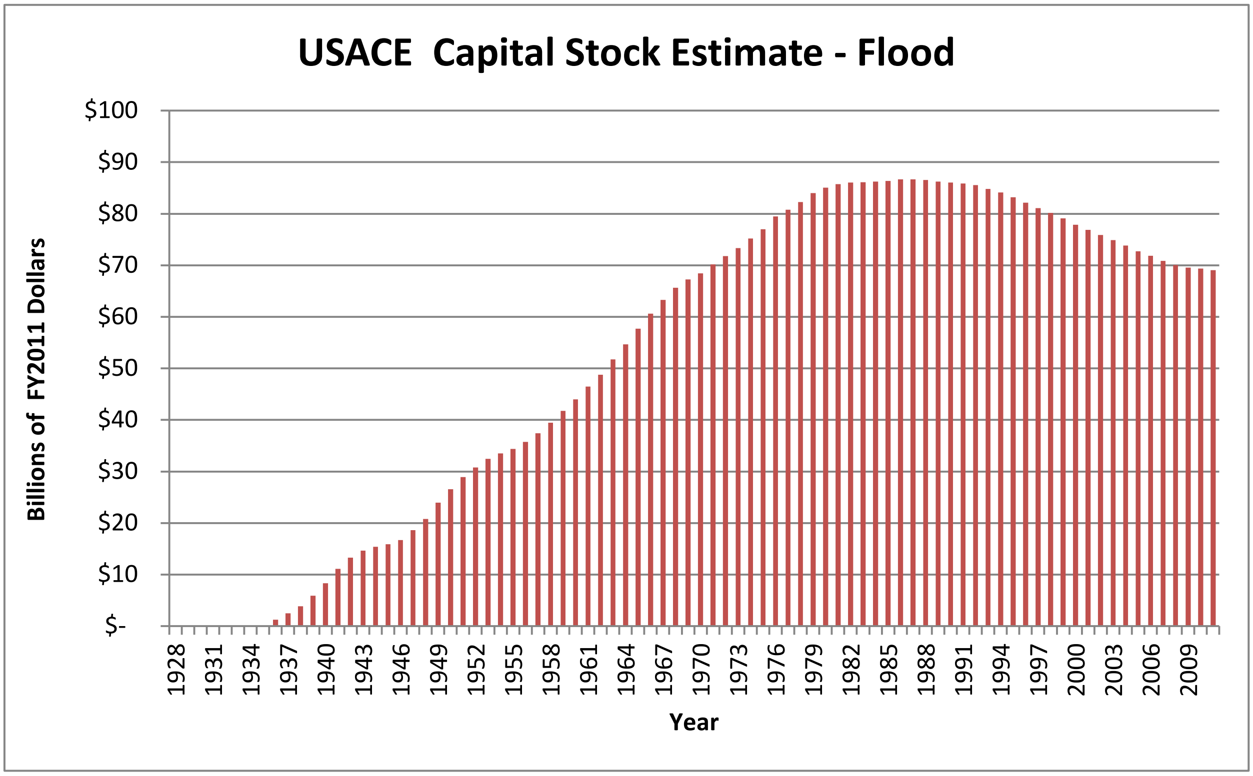

Figure 8
USACE Capital Stock Estimates for the Flood Risk Management Functional Category in Billions of 2011 Dollars

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

- The rate of investments (in 2011 dollars) made in this stock starting in 1936 remained relatively consistent through to 1986, increasing at an average rate of 0.57 percent per year.
- The USACE Flood Risk Management capital stock value peaks in 1986 at $86.7 billion. It then declines at a generally steady rate of 0.90 percent each year until present.
- The 2011 USACE Flood Risk Management capital stock value is $69.1 billion, or approximately what it was in 1970.

3.2.3 Multiple Purpose

Inventory Characterization

The Multiple Purpose 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 Multiple Purpose functional category and therefore, for the purposes of this study, all hydropower facilities are accounted for under the Multiple Purpose functional category. This infrastructure allows for the generation of 24 percent of the Nation's hydropower capability and three percent of the total electric capacity (USACE, 2012c). In addition, USACE hydropower plants generate more than $4 billion in gross annual revenue (USACE, 2011a).

Capital Stock Calculation

The calculation pertaining to the Multiple Purpose functional category is performed in the accompanying Microsoft Excel workbook. The chart of the final calculation is provided in **Figure 9**.

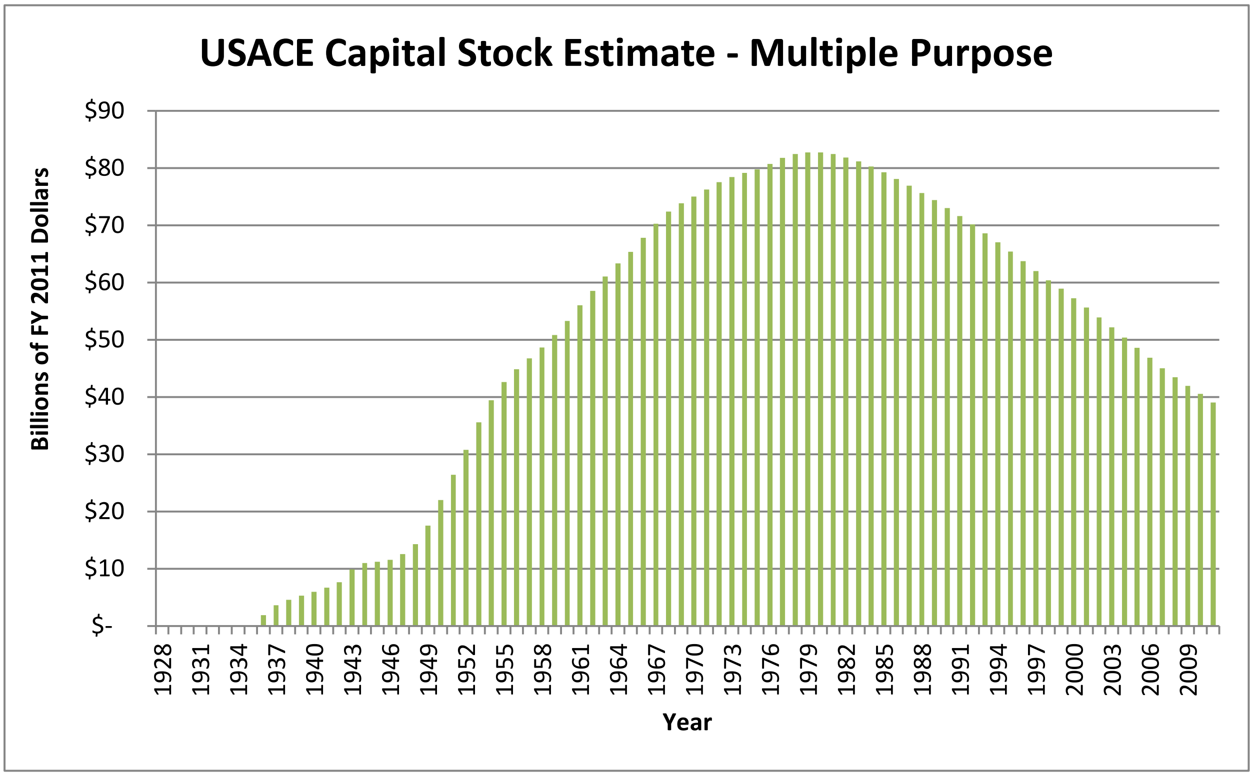

Figure 9
USACE Capital Stock Estimates for the Multiple Purpose Functional Cateogry in Billions of 2011 Dollars

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

- The rate of investments made in this stock starting in 1936 exhibited a relatively steep and steady growth rate through the early 1950s, increasing at an average rate of 5.9 percent annually from 1936 through 1953 (in 2011 dollars). Since 1953 investments in 2011 dollars have declined at an average rate of 3.1 percent annually.

- The peak USACE Multiple Purpose capital stock value occurred in 1980 at $82.8 billion.

- The average rate of decline from 1980 to 2011 is 2.4 percent annually.

- The 2011 USACE Multiple Purpose capital stock value is $39.1 billion, or approximately what it was in 1954.

3.2.4 MR&T

Inventory Characterization

The MR&T functional category consists of a variety of infrastructure including levees, navigation works, and dams. This functional category is unique in a number of 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. [18] Other MR&T assets includes 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. The chart of the final calculation is provided in **Figure 10**.

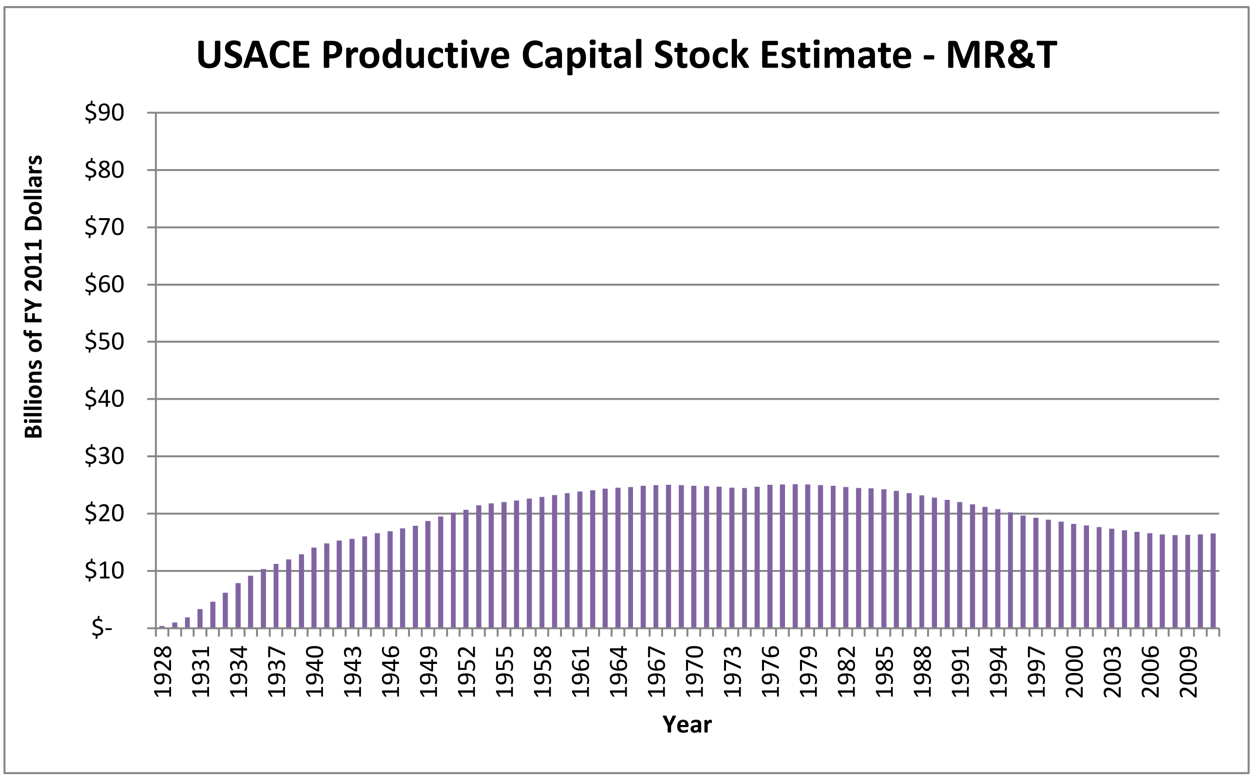

Figure 10
USACE Capital Stock Estimates for the MR&T Functional Category in Billions of 2011 Dollars

[18] 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).

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; investments increased at an average annual rate of 11.4 percent during this period. Since then investments in 2011 dollars have been variable, ranging from a high of $987 million in 1950 to a low of $117.9 million in 1996 and averaging $484.6 million annually.
- The peak USACE MR&T capital stock value occurred in 1978 at $25.1 billion.
- The average rate of decline from 1978 to 2011 is 1.3 percent annually.
- The 2011 USACE MR&T capital stock value is $16.5 billion, or approximately what it was in 1945.

3.2.5 Dredging

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

As mentioned earlier in this report, the Dredging functional category capital stock value is derived using a different set of assumptions that what are used for the other four USACE functional categories. In Section 2 above, 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, negatively impacts 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

Figure 11 and **Figure 12** show the annual investment in dredging maintenance and the estimated Dredging capital stock value from 1963 through 2011, respectively. Figure 11 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 upwards 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 the American Recovery & Reinvestment Act (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.

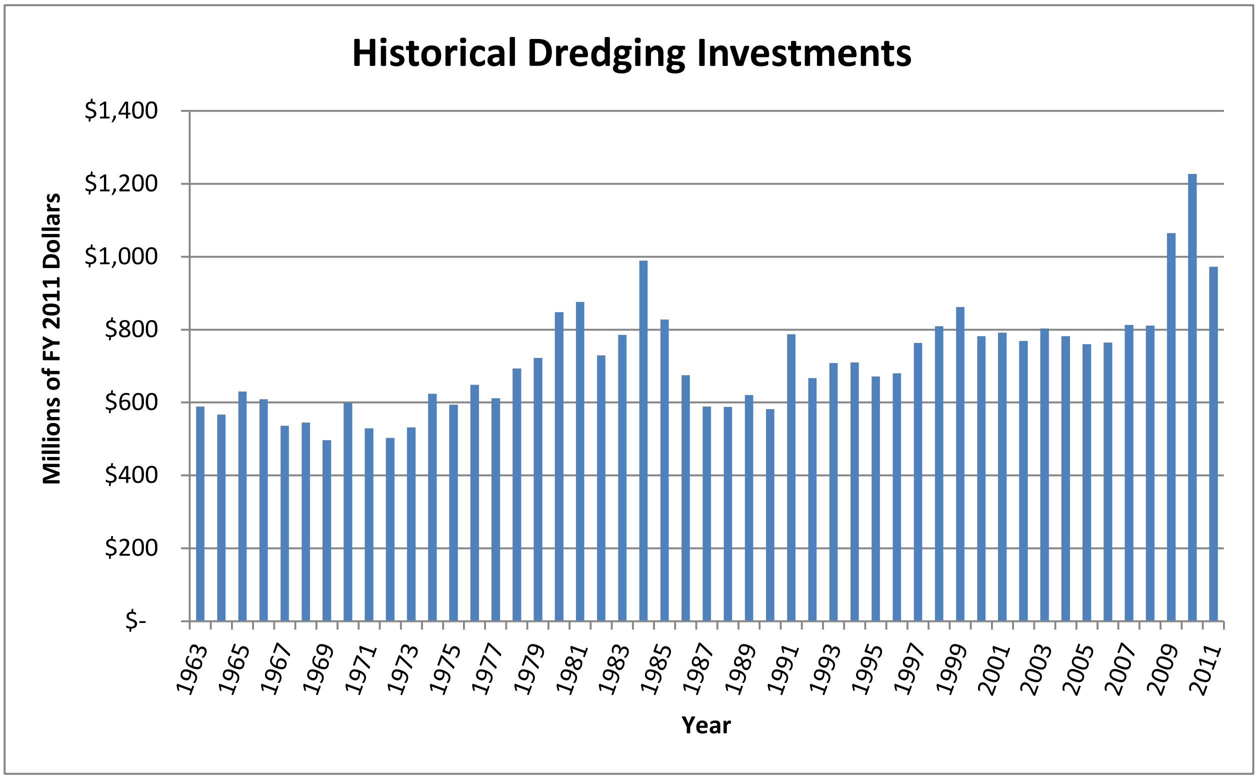

Figure 11
USACE Historical Dredging Investment, 1963 to 2011

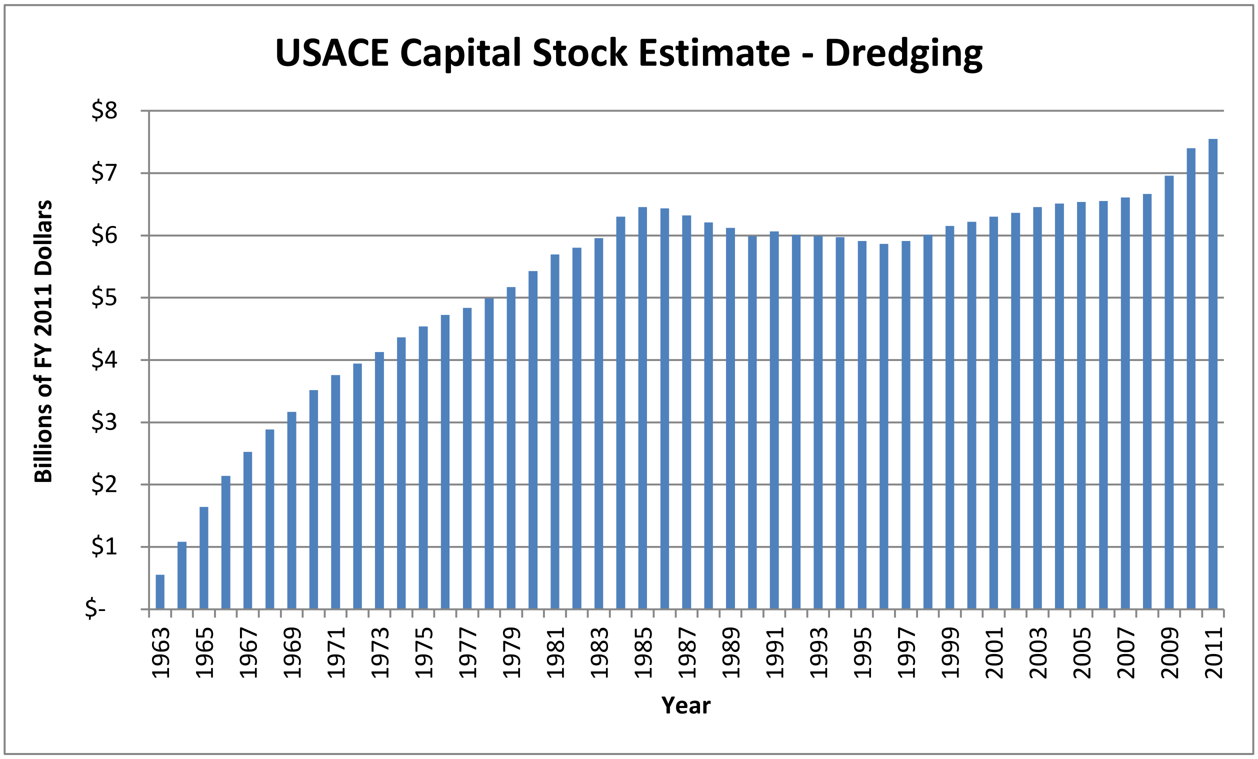

Figure 12
USACE Capital Stock, 1963 to 2011 – Dredging

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

- Dredging capital stock value has been growing at a relatively steady pace over the period of the analysis. The value grew steadily from 1963 through 1985, increasing at an average rate of 11.8 percent annually. Then the value declined until 1996, at which point it began growing again.
- The 2011 Dredging capital stock value of $7.8 billion represents the maximum (i.e., peak) dredging capital stock estimate.
- The 2011 Dredging functional category capital stock value represents 4 percent of the total USACE capital stock value.

Dredging Impact on Total Capital Stock Estimates

Dredging related capital stock has been growing steadily since 1963, as noted above. It has also been growing steadily on an annual basis as a percentage of total USACE water resources capital stock expenditures. **Figure 13** shows that in 2011, the Dredging functional category accounted for 21 percent of the total USACE Civil Works water resources capital stock investment.

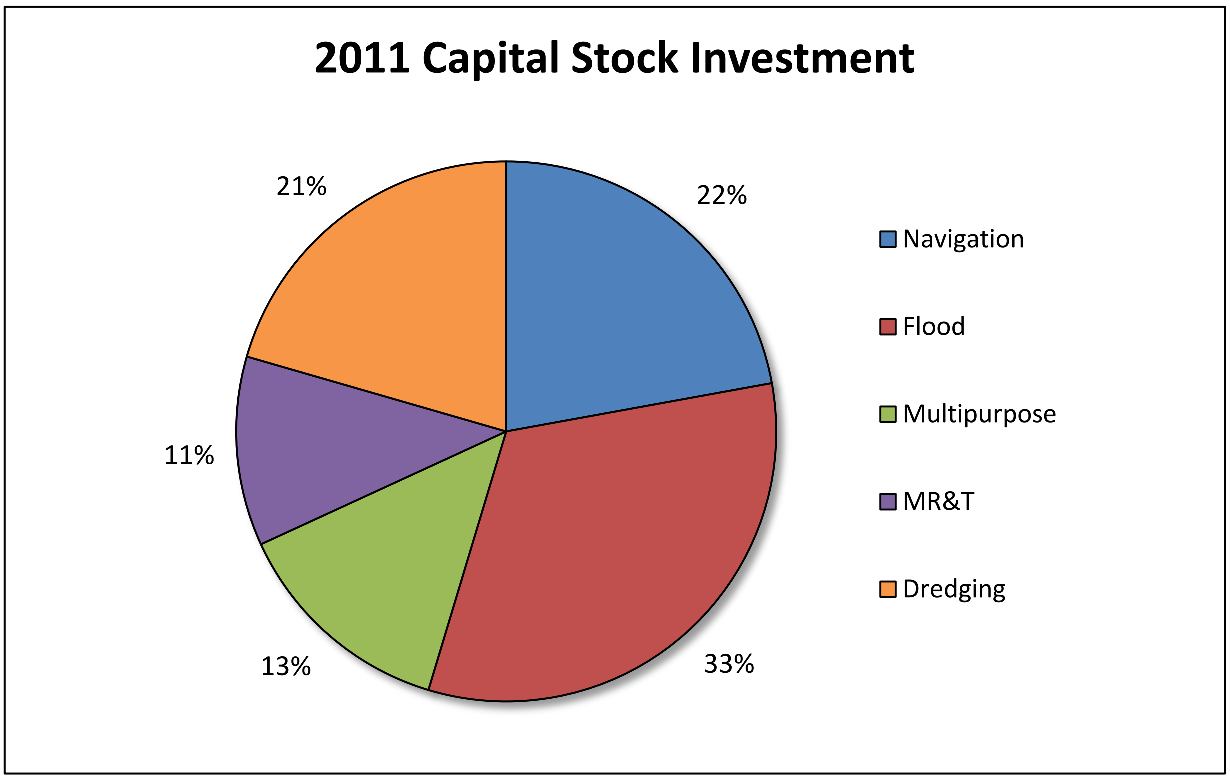

Figure 13
USACE Civil Works Capital Stock Investments, FY 2011

Despite the fact that 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 (Dredging is represented by the orange bars in **Figure 14**). At present, dredging accounts for 4 percent of the total USACE capital stock value. Accounting for the dredging expenditures in the PIM spreadsheet model results in an overall increase in the 2011 USACE capital stock value of $7.8. 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.

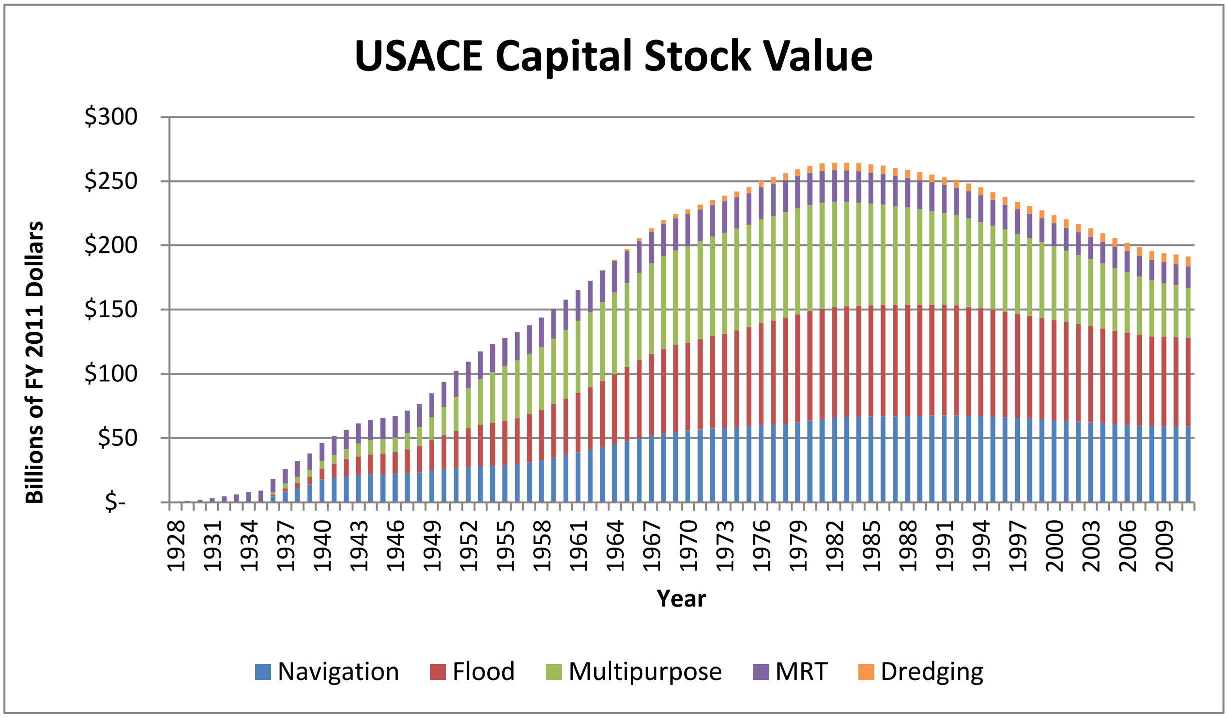

Figure 14
USACE Capital Stock Value Disaggregated by Functional Category

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. **Figure 15** below presents the aggregated USACE capital stock value.

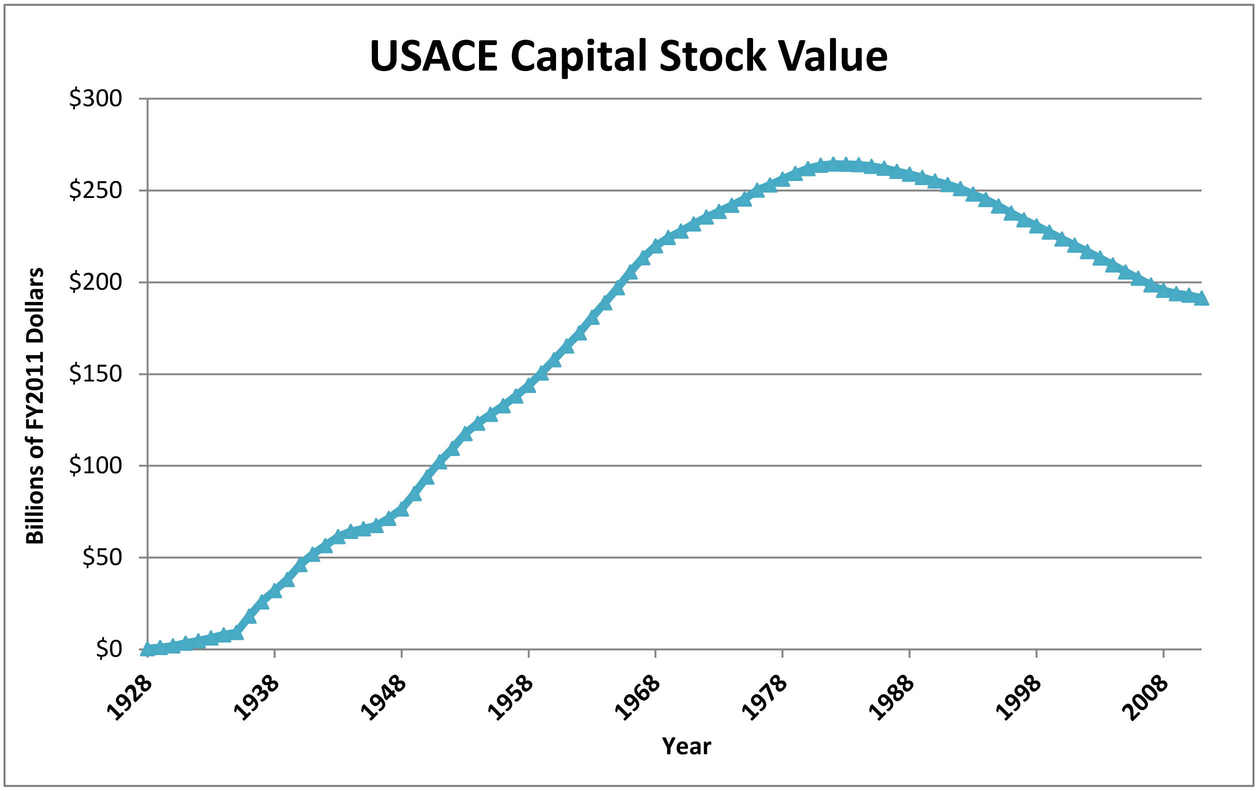

Figure 15
USACE Capital Stock Estimates, 1928 to 2011 in Billions of 2011 Dollars

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

- Annual Investment in USACE capital stock, in real dollars, peaked in 1966 at $10.7 billion (in 2011 dollars). Since 1966, investments have decreased at an average rate of 1.38 percent annually. Total capital stock investments in 2011 were $5.8 billion. These investments include Construction General account appropriations, allocated Unknown account appropriations, and Dredging expenditures.
- The USACE capital stock value peaked in 1982 at $264.4 billion. It then declined at an average annual rate of 1.1 percent through 2011.
- The 2011 USACE capital stock value is $191.4 billion, or approximately what it was between 1964 and 1965.
- Under the current study assumptions, over the next ten years $6.9 billion in annual investment would be required to sustain the capital stock value near its current level (see Figure ES-4). Anything less will result in further decline over that time frame. To compare, the Construction General account appropriations for fiscal years 2009, 2010, and 2010 were $2.1 billion, $2.0 billion, and $1.6 billion respectively. These appropriations include spending for major rehabilitation.

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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. First, an overview of the overall approach to the sensitivity analysis is introduced and provided. Presented next are sections that describe the sensitivity analysis with respect to the age-efficiency profile, the service life, and the hyperbolic function parameter estimate. The section closes with a summary and discussion of the results of the sensitivity analysis.

4.1 Monte Carlo Simulation Method Overview

The Monte Carlo simulation method is a computational algorithm that uses repeated random sampling to compute results of simulations of physical or mathematical system models. This method is commonly used to model phenomena with significant uncertainty in inputs. The general process employed to implement the Monte Carlo method is as follows:

1. Define a domain of possible inputs.
2. Generate inputs randomly from a probability distribution over the domain.
3. Perform a computation of the inputs.
4. Aggregate the results.

For this study, the Monte Carlo method is used to test the sensitivity of the USACE capital stock estimate with respect to three model inputs: the age-efficiency profile, the service life value, and the hyperbolic function value. The resulting range of capital stock estimates generated is presented to illustrate the calculation's sensitivity to the variability of each of the aforementioned inputs. The results of the Monte Carlo method are presented for each input variable in two ways. First, the upper and lower bounds of the capital stock estimate at the 95 percent confidence interval are presented to show the estimated range of probable results using input values within the defined domain. Second, a histogram of the calculation results are shown to illustrate the distribution of the estimate based on the defined domain of possible input values.

It should be noted that due to the limitations of the Monte Carlo sensitivity analysis application employed for this study, the input variable parameters are assumed for all functional categories. That is to say that the sensitivity to service life and the hyperbolic function value is based upon the use of a single mean and standard deviation values for these inputs and applied to all functional categories. Therefore, the results are solely meant to illustrate the sensitivity of the estimate to the parameter inputs and do not follow the structure of the study capital stock estimate where a different service life can be assumed for each functional category.

It should also be noted that the Dredging functional category is not included as part of the Monte Carlo sensitivity analysis. As was illustrated in Section 3, the Dredging functional category's impact on the overall USACE capital stock value was relatively insignificant and PIM assumptions differed from the other four functional categories and were not based on empirical evidence. Thus, it was determined that little value to the study was added by performing a sensitivity analysis on the Dredging functional category capital stock estimate.

4.2 Age-Efficiency Profile Sensitivity Analysis

The age-efficiency profile describes the pattern of productive efficiency of a capital stock portfolio as it ages, and is a critical assumption in calculating the capital stock value. Research on the subject supports the use of a hyperbolic deterioration function in estimating capital stocks. However, for the purpose of understanding the range of 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 16**).

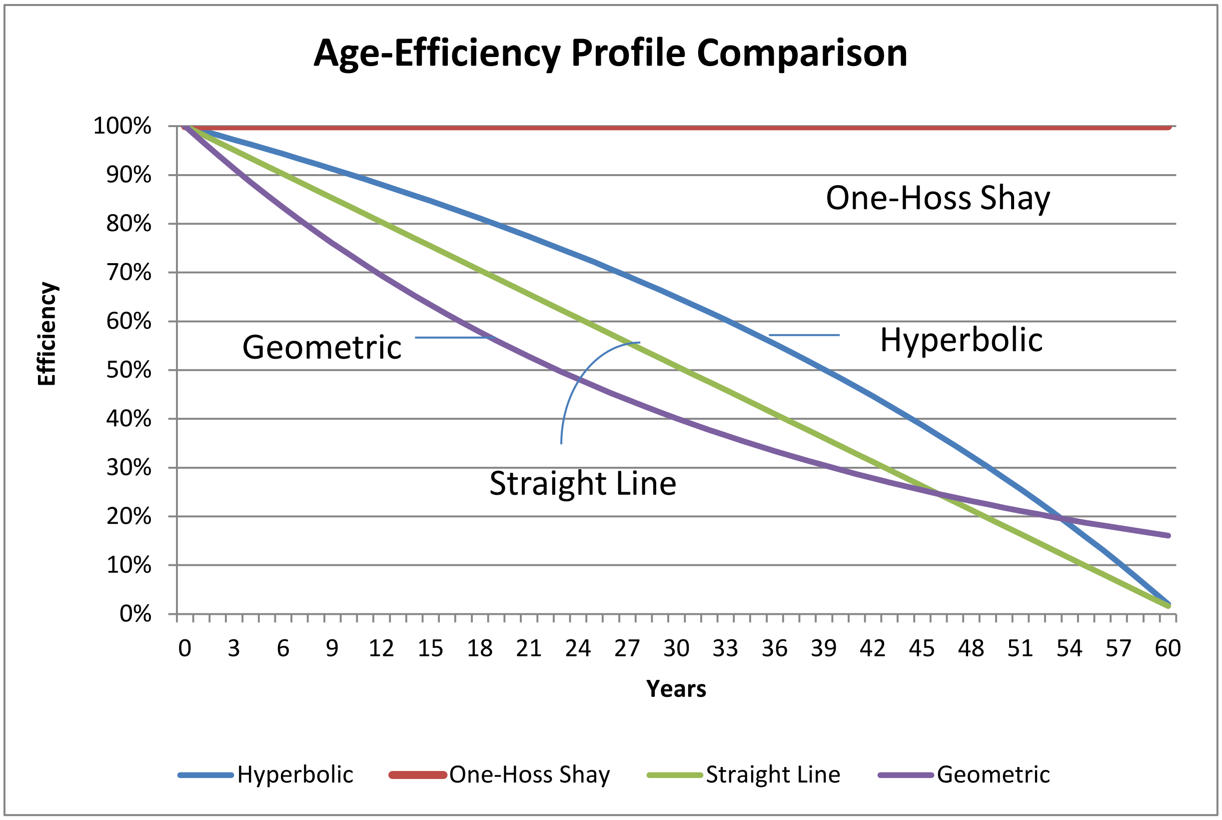

Figure 16
Age-Efficiency Profile Comparison

The capital stock estimates derived using each age-efficiency profile were compared to the hyperbolic function selected. The results are shown in **Figure 17**.

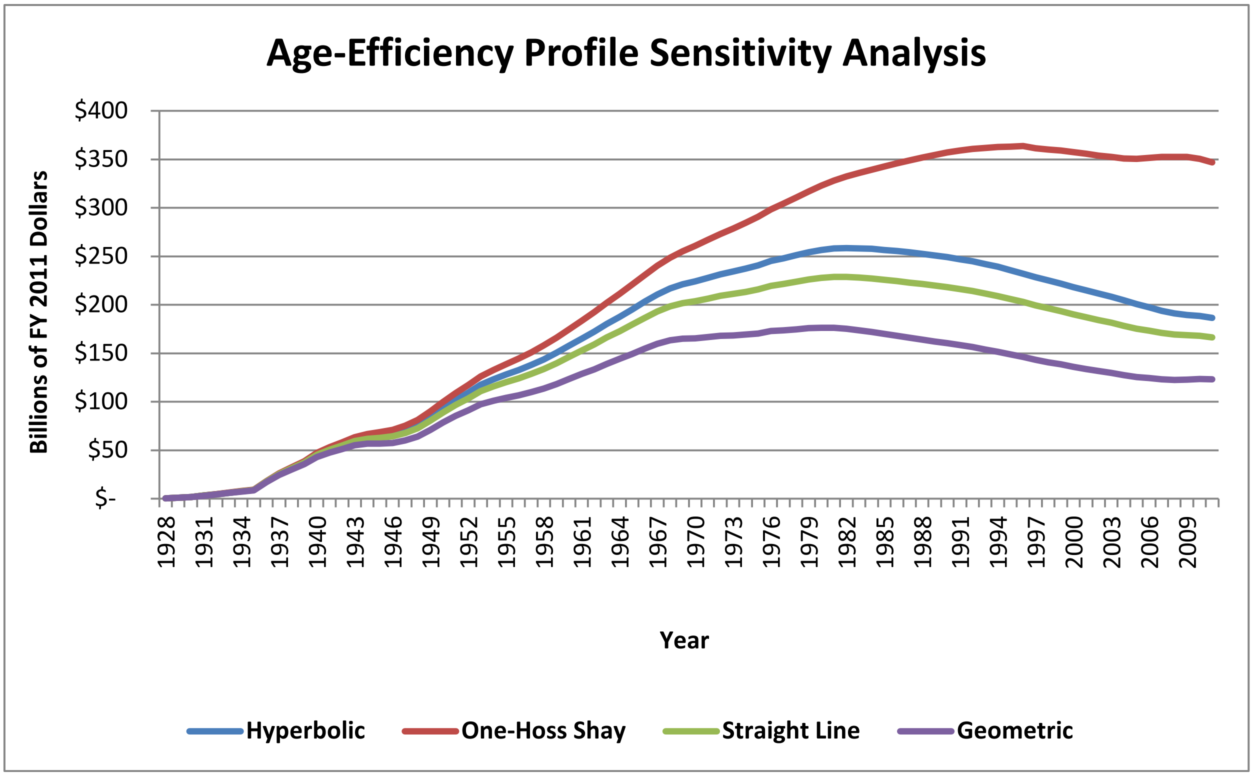

Figure 17
Capital Stock Calculation Age-Efficiency Profile Sensitivity Analysis

Varying the age-efficiency profile creates a significant variation in the results of the analysis, excluding the Dredging functional category. The range of results for the current (i.e., 2011) capital stock value varies from $346.9 billion when using a One-Hoss Shay retirement profile, to $123.4 billion when using a geometric profile, keeping in mind that these results exclude the Dredging capital stock value. This output indicates a range of $223.5 billion in the potential outcomes for 2011. However, the results for the One-Hoss Shay profile are an outlier compared to the other three outcomes which have a relatively small range of $63.3 billion separating them.

The results are intuitive based on the age-efficiency profiles (Figure 16), in that the value of the 2011 USACE capital stock is a function of the deterioration patterns of the age-efficiency profiles, and the asset value curves descend in order relative to the age-efficiency profiles that maintain the level of service of the underlying assets the longest. 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 a 60-year service life, USACE has not yet begun experiencing significant deterioration in its capital stock. Given that significant investments for USACE capital stock did not begin until 1936 (see Figure 6) and the assumed service life of an asset is 60 years, in this model USACE has only seen significant deterioration of capital stock value over the last 15 years. Using a shorter service life assumption would alter the results to be more in line with the other alternatives.

In examining the other three age-efficiency profiles, it can be seen that the general shape of each of the resulting curves is the same. The peak years are 1982 for the hyperbolic function and straight-line function and 1980 for the geometric function.

4.3 Service Life Sensitivity Analysis

The findings of this sensitivity analysis affirms that the selection of a 60-year service life assumption with a standard deviation of 15 years would be both a reasonable assumption and consistent of with capital stock theory (OECD, 2009) and authoritative sources (BEA, 1999). It should be noted that in the final analysis, the navigation service life was increased to 75 years for empirical reasons. The service lives of the other components remained at 60. The sensitivity analysis reported in this section is informative, but does not directly apply to the final analysis In preparing the simulation; it is assumed that service life variability will follow a normal probability distribution. In preparing the normal distribution, the following service life parameters have been set:

- Mean: 60
- Standard Deviation: 15
- Upper and Lower Bounds at the 95 Percent Confidence Interval

The Monte Carlo simulation on the USACE capital stock was run for 1,000 trials showing the results for both the mean values and 95 percent confidence intervals. The results shown in **Figure 18** indicate that the mean outcome for the analysis is a capital stock value of $175.4 billion in 2011. This total excludes the capital stock value of the Dredging functional category and includes major rehabilitation investments. This mean is slightly lower than the median value ($175.6 billion), indicating little skewness in the distribution of the simulation's results. In FY 2011 the results for the 95 percent confidence interval is $79.1 billion using the lower boundary assumptions and $279.6 billion using the upper boundary assumptions. The range of probable results is $200.5 billion; more than quadruple that of the hyperbolic parameter (see section 4.4 below), indicating that the model has a high level of sensitivity to the service life input. This level of sensitivity aligns with previous conclusions of the sensitivity of capital stock models to service life.

This distribution of the simulation results are illustrated graphically in **Figure 19**. This figure shows that, given the input parameters described above, the greatest number of Monte Carlo simulations resulted in a 2011 capital stock value between $170 billion and $230 billion. These distribution results, along with the mean capital stock value of $175.4 billion derived from the service life sensitivity analysis, are on par with the USACE 2011 capital stock estimate (assuming 60 year service life) of $183.8 billion ($176.2 billion without accounting for the Dredging functional category) as presented in Section 3.3 of this report. As mentioned, these Monte Carlo findings are not directly applicable to the final results of $191.4 billion and $183.6 billion without dredging. Nevertheless, they are informative and do indicate the importance of the service life assumption.

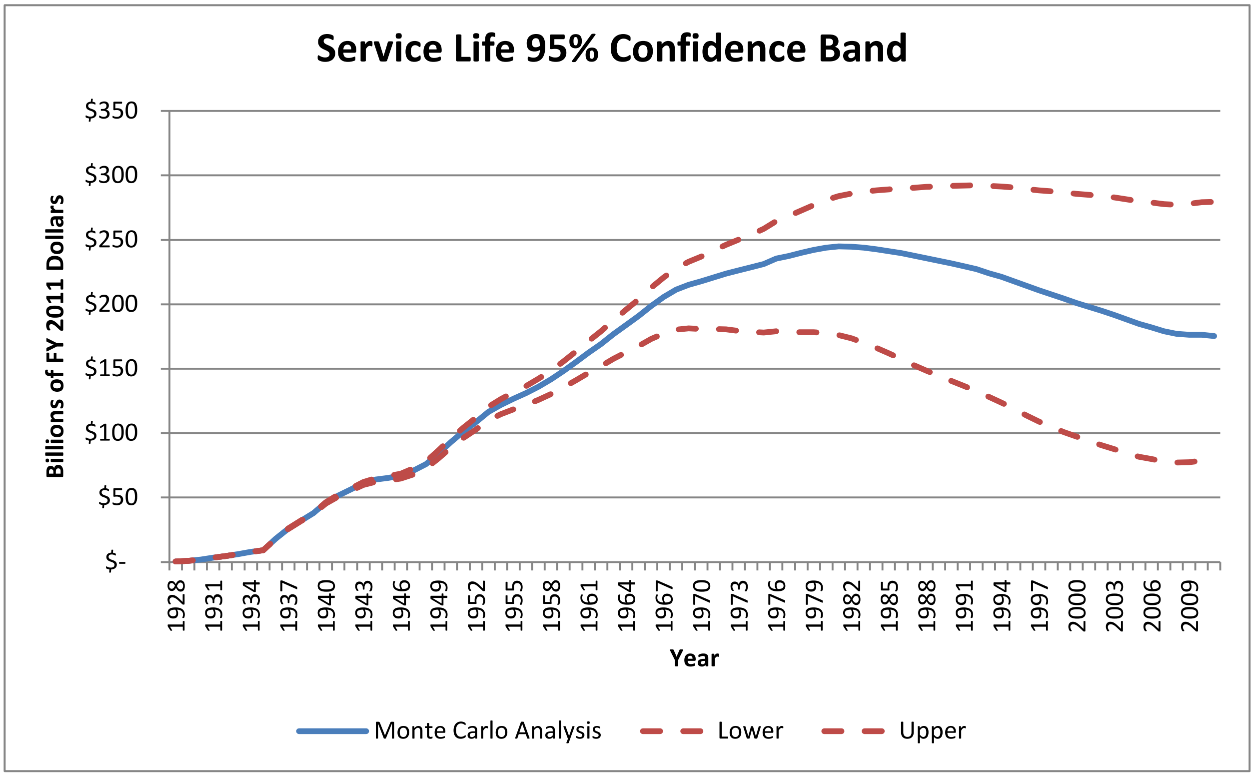

Figure 18
Service Life Input Parameter Monte Carlo Simulation Results

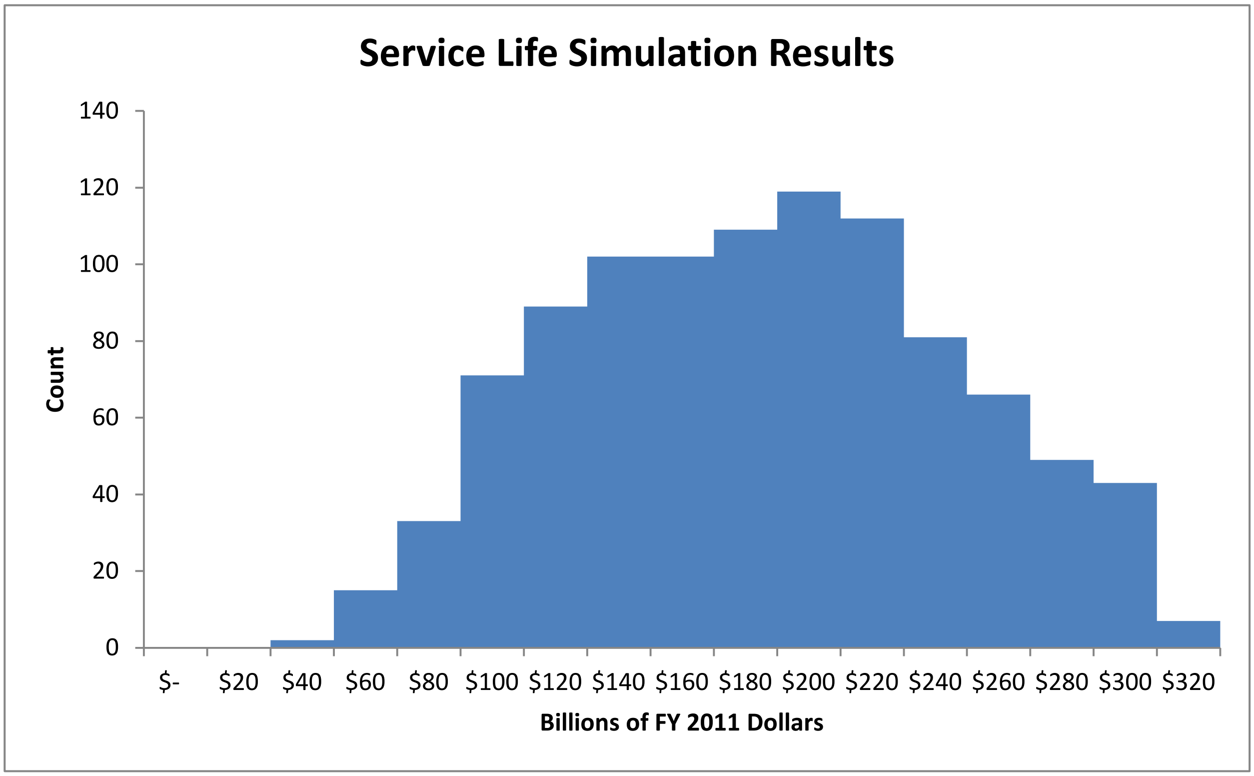

Figure 19
Service Life Assumption Sensitivity Analysis Distribution of Net Capital Stock

Figure 19 is meant to illustrate the distribution of the simulation results, showing the number of simulation iterations by the capital stock value results. Illustrating the results in this manner is useful in understanding how the simulation results were distributed given the above input parameters and is complimentary to Figure 18 which shows only the upper and lower bounds of the statistically significant results as well as the mean value over time. The distribution shows a normal distribution of capital stock value results around the mean.

4.4 Sensitivity Analysis of Hyperbolic β Parameter Assumptions

This section examines the sensitivity of the capital stock estimate with respect to the values used for the hyperbolic (i.e., deterioration) parameter. [20] As mentioned in this report, observation of USACE capital stock inventory indicates the preferred age-efficiency profile is a hyperbolic function with a β factor between zero and one ($0 < \beta < 1$). These boundaries are necessary because any values outside of the boundaries would create negative deterioration rates (i.e., an asset is increasing in value over time) which is an impossible result.

In preparing the simulation, it is assumed that beta factor variability will follow a normal probability distribution. In preparing the normal distribution, the following parameters have been set:

Beta factor:

- Mean: 0.6
- Standard Deviation: 0.1
- 95 Percent Confidence Interval

The results of the analysis shown in **Figure 20** indicate the mean outcome is $177.9 billion. This total excludes the capital stock value of the Dredging functional category and includes major rehabilitation investments. The mean is slightly higher than the median, which is $176.4 billion, indicating skewness in the distribution of the simulation's results. In FY 2011 the results for the 95 percent confidence interval is $155.6 billion at the lower boundary and $204.9 billion at the upper boundary. The range of probable results is $49.2 billion, indicating that the model has a relatively low level of sensitivity to the hyperbolic parameter input compared to the service life input.

The distribution of the simulation results are shown in **Figure 21**. This figure shows that, given the input parameters described above, the greatest number of Monte Carlo simulations resulted in a 2011 capital stock value between $170 billion and $190 billion. These distribution results, along with the mean capital stock value of $176.4 billion derived from the hyperbolic function sensitivity analysis, are on par with a USACE 2011 capital stock estimate of $183.8 billion ($176.2 billion without accounting for the Dredging functional category) derived using a 60 year life for all components).

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

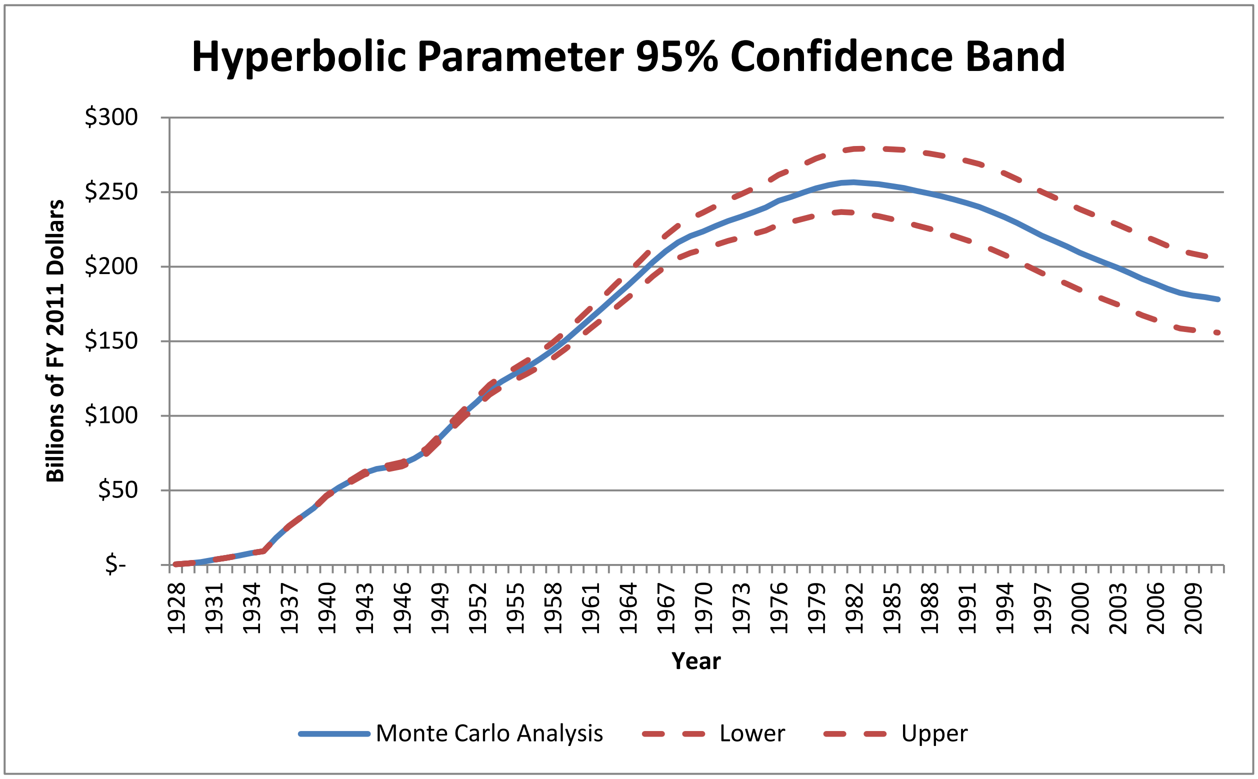

Figure 20
Results of the Monte Carlo Analysis Simulating Variability in the Hyperbolic Function Assumption

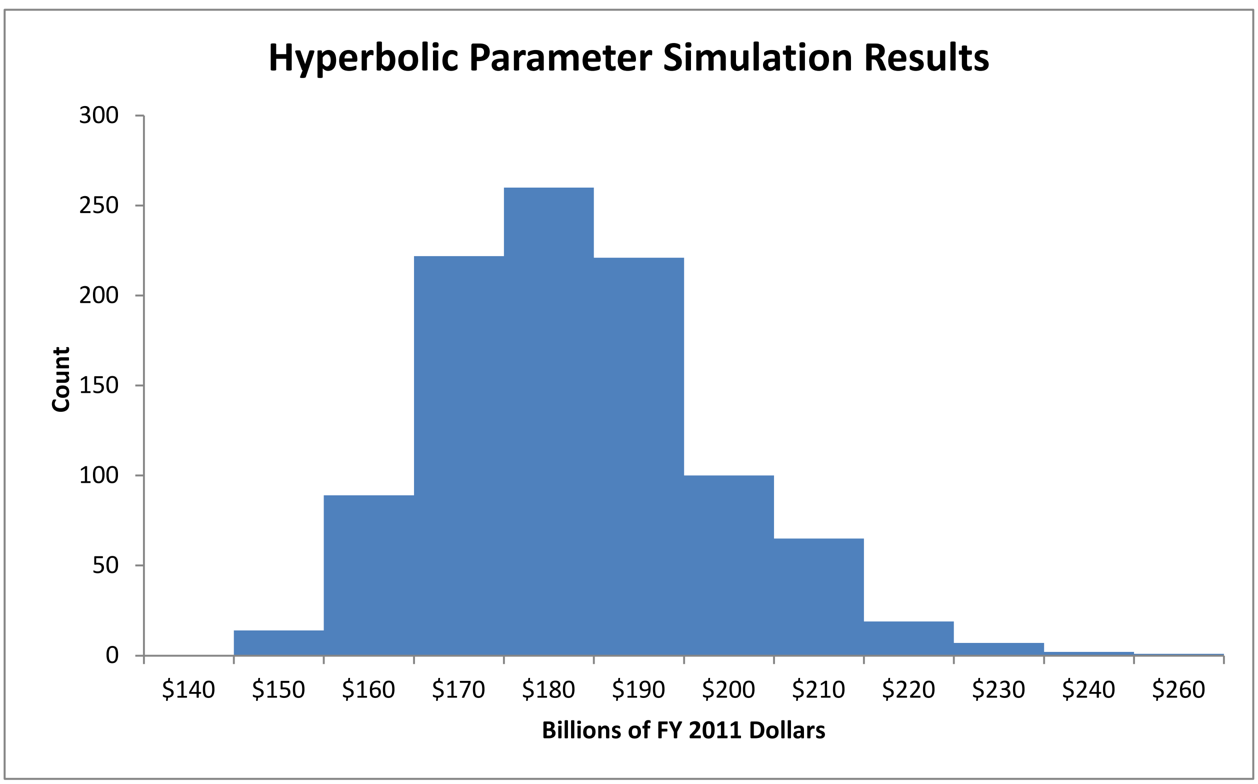

Figure 21
Distribution of Capital Stock Analysis Simulation Results Using Variability in the Hyperbolic Parameter Assumption

4.5 Multivariate Sensitivity Analysis

This section describes the results of the sensitivity analysis when alternative values for retirement age and age-efficiency profiles are used given certain boundary conditions. In performing this portion of the sensitivity analysis, it is assumed both the service life and hyperbolic parameter distributions presented in Section 4.3 and Section 4.4, respectively, are used. The results of the multivariate sensitivity analysis do not include the capital stock value estimates for the Dredging functional category nor major rehabilitation investments. The results of the multivariate sensitivity analysis are shown in **Figure 22**.

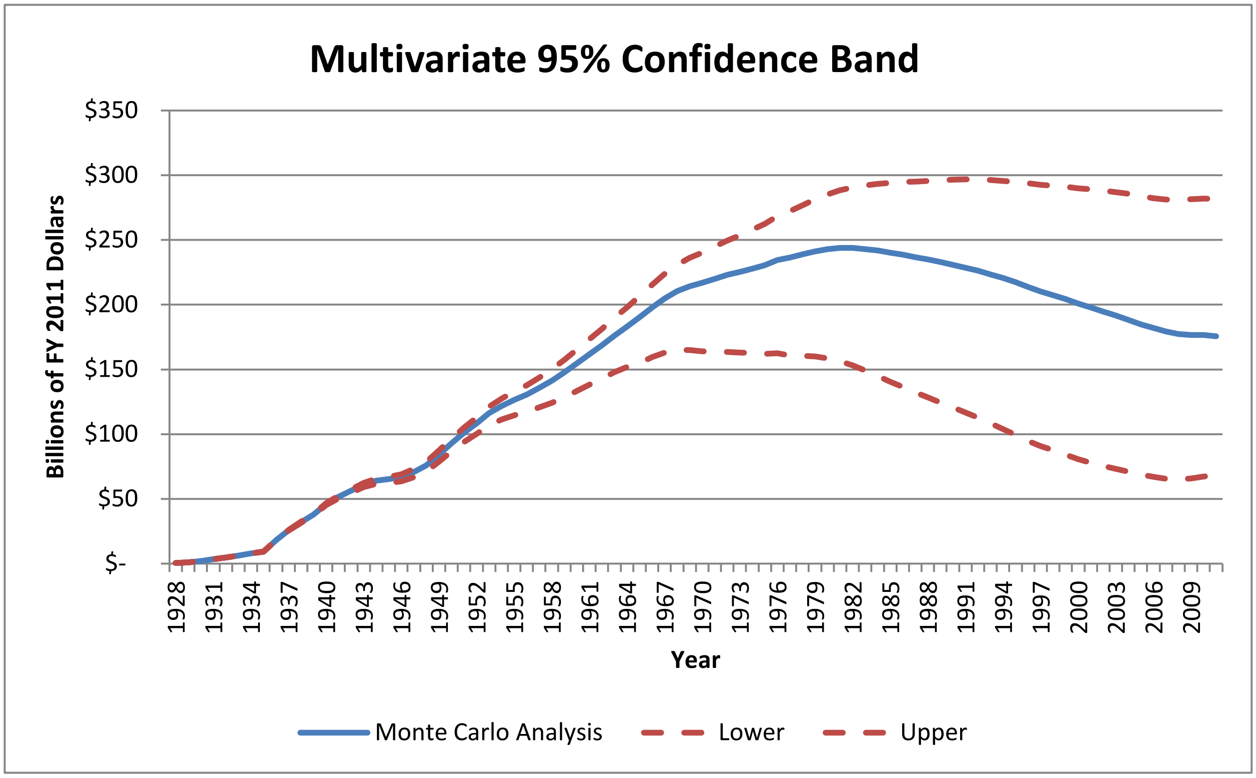

Figure 22
Multivariate Capital Stock Sensitivity Analysis

The results of the multivariate sensitivity analysis indicate that the mean outcome for the FY 2011 capital stock valuation, excluding Dredging, is $175.7 billion. The median, at $174.7 billion is slightly lower than the mean.

The distribution of the multivariate simulation results are shown in **Figure 23**. This figure shows that, given the input parameters described above, the greatest number of Monte Carlo simulations resulted in a 2011 capital stock value between $160 billion and $200 billion. These distribution results, along with the mean capital stock value of $175.7 billion derived from the multivariate sensitivity analysis, are on par with the USACE 2011 capital stock estimate (assuming 60 year service life for all components) of $183.8 billion ($176.2 billion without accounting for the Dredging functional category).

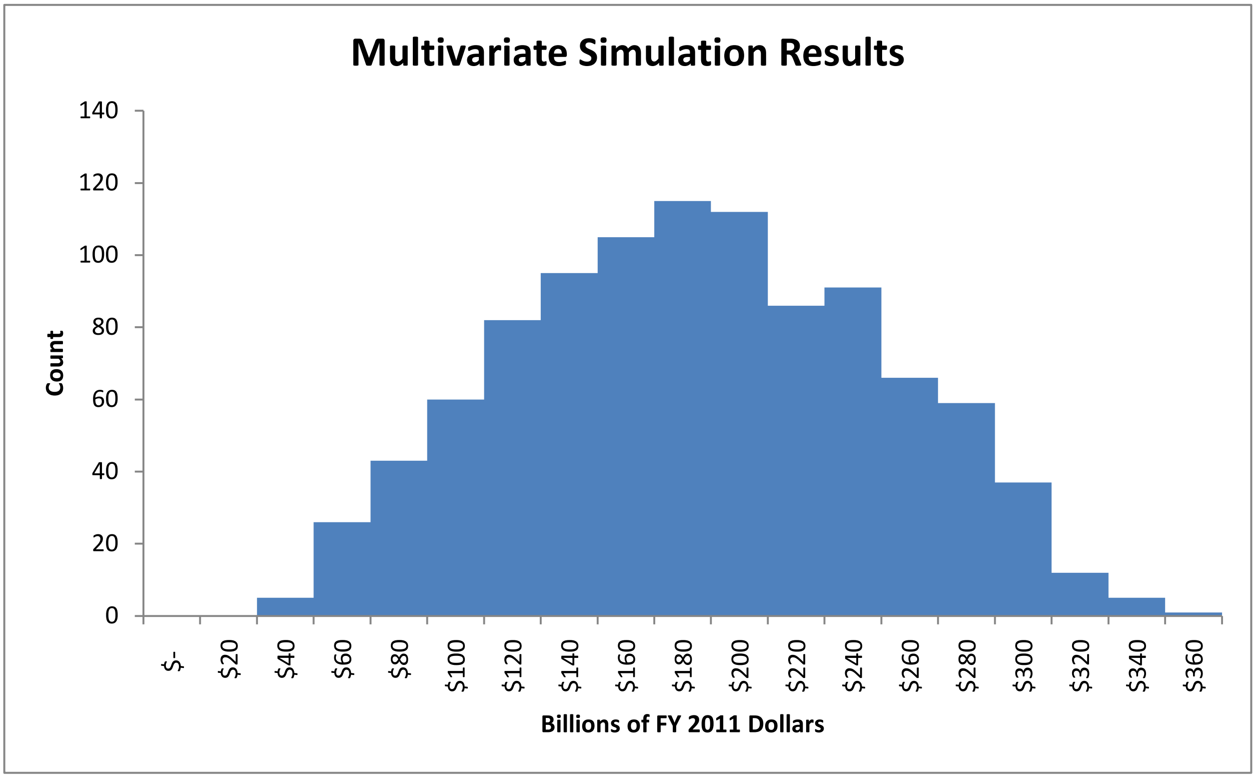

Figure 23
Capital Stock Sensitivity Analysis: Histogram of Capital Stock Values Using Multivariate Assumption Variability

In FY 2011 the results for the 95 percent confidence interval for the multivariate parameter sensitivity are $68.1 billion on the lower boundary and $281.8 billion on the upper boundary. The range of probable results is $213.6 billion, indicating that the model has a high level of sensitivity to the input parameters.

The results for the mean and median capital stock value of the multivariate sensitivity analysis lie in between the range identified in the individual parameter sensitivity analyses for service life and the beta function. Also, as would be expected, the range of possible outcomes has expanded, since a larger number of variables in the analysis inherently create more uncertainty in the outcome.

4.6 Sensitivity Analysis Conclusions

Although there remains a measurable uncertainty with the assumptions driving the application of the PIM, considering reasonable ranges, the integrity of the calculation is maintained throughout, meaning that the overall trends and behaviors of the calculation are similar when examining a range of possible assumption inputs. Specifically, regardless of the age-efficiency profile used or the variation of input assumptions examined, the overall trend, which is a declining level of capital stock value, holds true.

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Section 5

Findings and Conclusions

This section presents findings of the calculation and sensitivity analysis, making key observations as well as 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. A further objective of this analysis was to incorporate advancements in the PIM employed from previous efforts based on advancements to the underlying theory. This study makes four notable advancements from prior studies.

- First, it increases the asset retirement age from 50 years to 60 years for the Flood Risk Management, Multipurpose, and MR&T functional categories. For the Navigation functional category, the asset retirement age has increased to 75 years. The two previous studies assumed the average retirement age of USACE civil works capital assets to be 50 years. However, using data from the Chief of Engineers Annual Report, the current average age of USACE projects was computed and discovered to be greater than 50 years for each of the functional categories, excluding Dredging and well over 50 years for the Navigation functional category. These findings as well as U.S. BEA data were used to support the service life assumptions for this study.

- Second, the current study includes dredging as a special case of the sustainment of the capital stock value of navigation channels. Dredging capital stock value is estimated for this study and contributes to the total current and historical USACE Civil Works water resources capital stock value.

- Third, prior studies did not account for the impact of major rehabilitation investments to sustain capital stock. The current study uses available major rehabilitation investment data to account for the impact of these expenditures on the capital stock value over time.

- Fourth, a Monte Carlo simulation is employed to evaluate assumption sensitivities, recognizing a substantial amount of uncertainty remains in them principally due to data limitations.

Figure 24 presents the summary of USACE capital stock value derived from this study. The 2011 value of the capital stock is estimated to be $191.4 billion. This value represents a decline of 27.6 percent from the stock's highest value of $264.4 billion at its 1982 apex. The service life assumption of 60 years for the Flood Risk Management, Multiple Purpose, and MR&T functional categories used in this analysis portends that much of the aging infrastructure built in the 1950s, and represented in the current stock shown in Figure 24, are beginning to exit the portfolio. A similar observation can be made with respect to Navigation infrastructure built since the late 1930s. More importantly, to the degree that the assumptions built into the PIM have fidelity to real life, it can be assumed that as these assets age and deteriorate the services that they provide to the Nation will degrade.

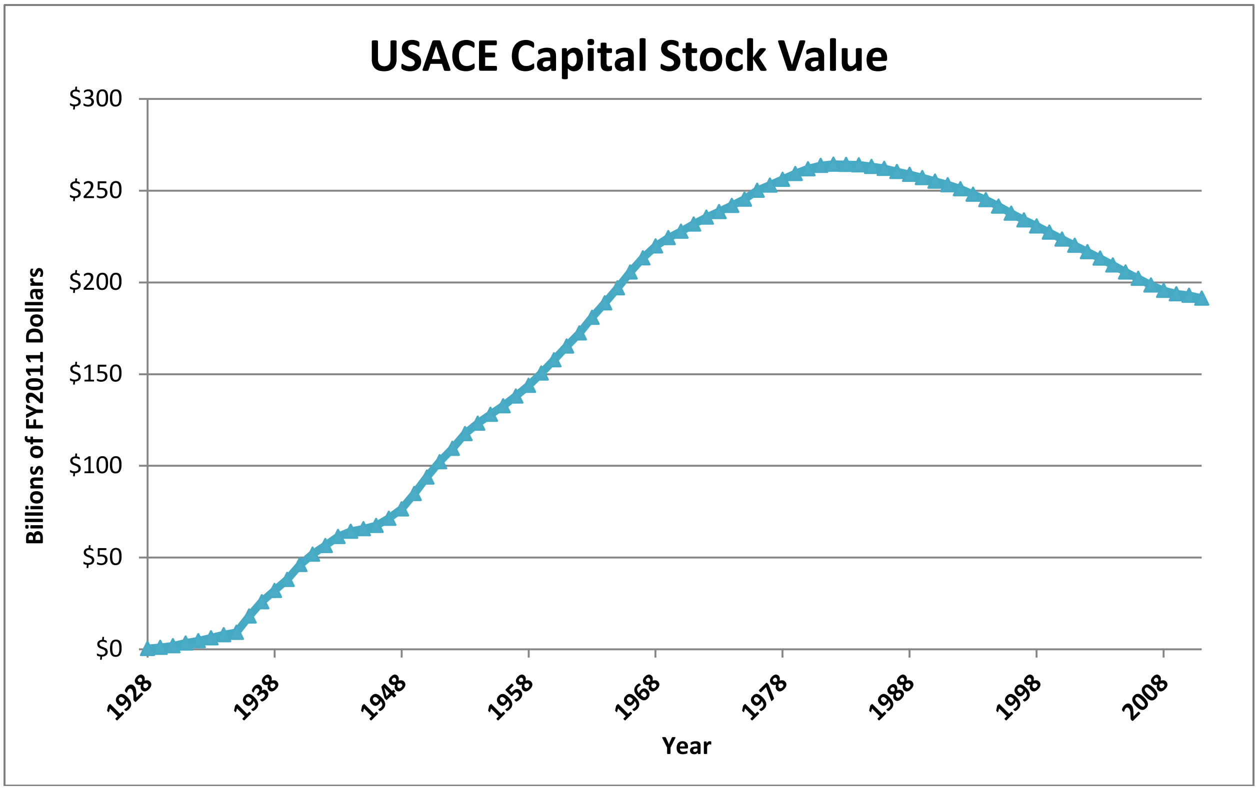

Figure 24
USACE Capital Stock 1928 to 2011

Figure 25 shows the pattern of net USACE capital additions over the period 1928 to 2011. Net USACE capital additions are calculated as the difference between USACE investment and retirements. The net USACE capital additions estimate is directly linked to the USACE capital stock estimate presented in Figure 24 because it factors in historical investments and retirements. Over time, as investments have declined and retirement of assets has increased due to more assets reaching their assumed service life, net USACE capital additions have become negative, indicating that retirements exceed investments. Figure 6 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 retirements coalesced to result in a sustained period whereby retirements exceed investments. This point in time coincides with the point in time when the USACE capital stock estimate begins its sustained period of decline as shown in Figure 24.

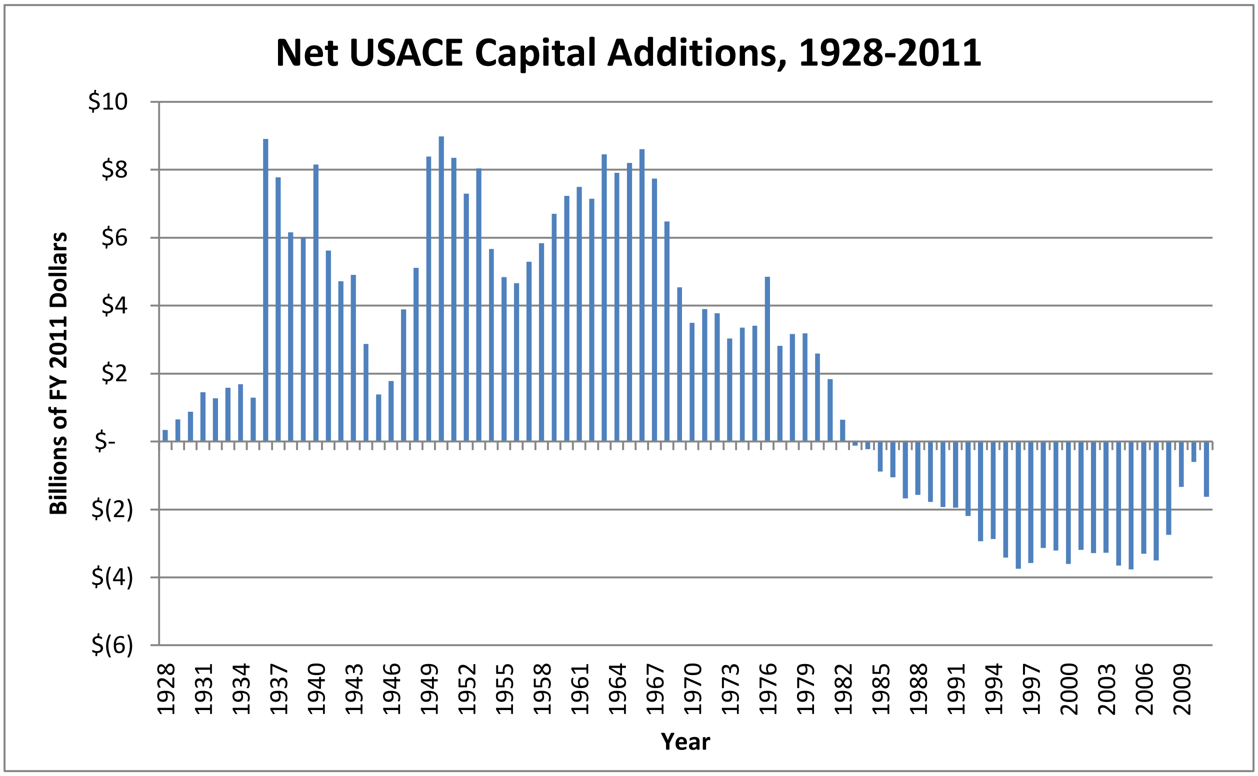

Figure 25
Net USACE Capital Additions, 1928 to 2011

The Monte Carlo simulation completed for this study shows that the trends and behavior of the capital stock calculation were maintained when a range of inputs for the service life and hyperbolic parameter were tested to analyze sensitivity of the calculation to these input assumptions. The mean USACE capital stock values can vary substantially (up to $200 billion from lower bound to upper bound) when examining a large range of parameter inputs. The results indicate that, though the capital stock estimate is sensitive to the input values for service life and hyperbolic age-efficiency parameter, the capital stock value estimated for this study is similar in value to the mean and median capital stock values generated by the Monte Carlo simulation using a range of probable inputs.

5.2 Comparison to 2003 Capital Stock Estimation Study

This sections provides a comparison of the 2011 capital stock value as derived using the service life and beta function assumptions applied to this study and those assumptions used for the previous capital stock report developed in 2003. For this comparison, the 2011 value is shown for scenarios with and without the additions of the Dredging functional category and historical major rehabilitation expenditures. **Table 3** below provides a comparison of these scenarios.

As Table 3 shows, extending the service life assumption and decreasing the hyperbolic beta value for this study generates a 2011 capital stock estimate that is only slightly (1.2 percent) higher than if those assumptions used for the 2003 were applied.

Table 3: Comparison of 2011 Capital Stock Estimate Using Previous Study Assumptions and Updated Study Assumptions

Scenario	Service Life	Beta	2011 Value (billions)
1 - Without Dredging and Major Rehabilitation	50 Years – All Categories	0.9 – All Categories	$171.9
2 - With Dredging and Major Rehabilitation	50 Years – All Categories	0.9 – All Categories	$189.1
3 – Without Dredging and Major Rehabilitation	75 Years – Navigation 60 Years – All Other	0.5 – Navigation 0.6 – All Other	$173.4
4 – With Dredging and Major Rehabilitation	75 Years – Navigation 60 Years – All Other	0.5 – Navigation 0.6 – All Other	$191.4

5.3 Analysis of Navigation Service Life Uncertainty

As discussed in Sections 2.3.3 and 3.2.1 of this report, it was observed that the average age of current USACE navigation projects are significantly higher compared to USACE projects comprising the other functional categories. Upon discussions with USACE reviewers as well as representatives from the BEA and the Bureau of Labor Statistics (BLS) it was determined that the assumed Navigation functional category service life should be longer than all other functional categories As a result, the Navigation functional category service life assumption was assumed to be 75 years. Furthermore, the aforementioned analysis and discussions confirmed that 60 years is an appropriate service life assumption for the Flood Risk Management, Multipurpose, and MR&T functional categories.

It is recognized that there is still uncertainty with respect to the Navigation functional category service life assumption. The Monte Carlo service life sensitivity analysis for all functional categories excluding Dredging exhibited a very large range of capital stock estimates at the 95 percent confidence interval. While this range provided a useful illustration of the capital stock estimate's sensitivity to the service life input, it was determined to be of limited value in reporting a suitable current USACE capital stock estimate range. Therefore, Navigation was treated as a special case and the results of the capital stock estimate using a ±10 year Navigation service life range (i.e. 65 – 85 years) was generated to provide range of capital stock values capturing the uncertainty of the Navigation functional category service life assumption.

The range of capital stock values over time generated from this analysis is shown in **Figure 26**. The 2011 capital stock value range shown in Figure 26 is $179 billion with the high end of the range at $200.3 billion and the low end of the range at $182.4 billion. The red line shown in the figure is the capital stock estimate using the assumptions presented in this report and has a 2011 value of $191.4 billion.

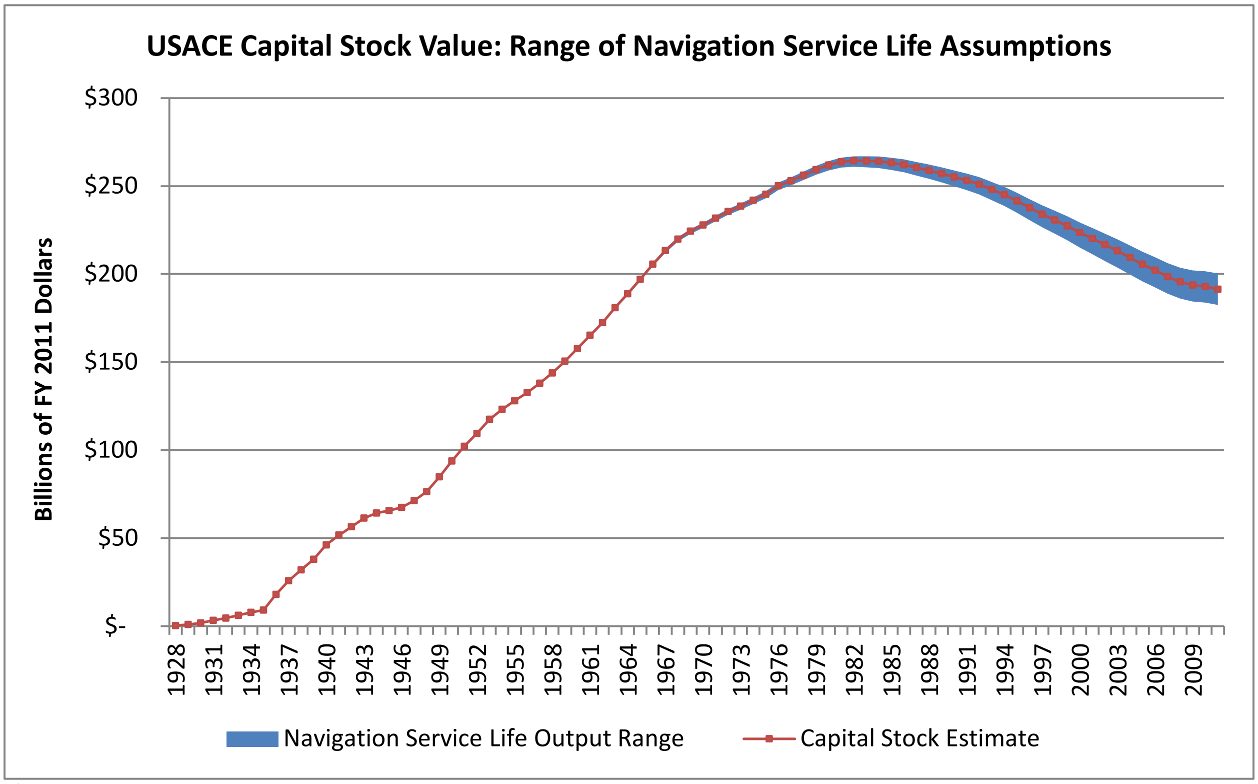

Figure 26
USACE Capital Stock Value Range

5.4 Key Observations

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

- The USACE capital stock value exhibits the greatest sensitivity to the service life input parameter. The Monte Carlo simulation performed for this study shows that the 2011 estimate at the upper and lower bounds of statistical significance resulted in an output range of $272 billion for the service life input parameter, $97 billion for the hyperbolic beta function parameter, and $141 billion for the multivariate (i.e., service life and hyperbolic beta function) parameters.

- The 2011 mean USACE capital stock value calculated using the Monte Carlo simulation did not differ substantially for any of the input parameters. The 2011 capital stock value is calculated as $191.4 billion ($183.6 billion without the Dredging functional category which is not considered in the Monte Carlo analysis). The 2011 mean capital stock value for the service life Monte Carlo simulation is $175.3 billion. The 2011 mean capital stock value for the hyperbolic beta parameter Monte Carlo simulation is $177.9 billion. The 2011 mean capital stock value for the multivariate Monte Carlo simulation is $175.7 billion. It should be noted that the Monte Carlo simulation results assume a 60 year service life for all functional categories excluding Dredging while the 2011 capital stock estimate assumes a 75 year service life for the Navigation functional category and 60 years for all other functional categories excluding Dredging. Thus, the simulation results are informative, but not directly applicable to the final result that uses 75 years.

- Since the early-1980s the capital stock value has declined by 27.6 percent. Part of this decline is due to a shift from massive, multipurpose projects to smaller, single purpose projects. The infrastructure continues to generate benefits that contribute to our Nation's safety, quality of life, and economic competitiveness, as is 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 should continue to decline, the Civil Works water resources infrastructure will deteriorate to a level whereby these benefits will begin to be diminished, and services erode. Replenishing the stock of deteriorated infrastructure will be no simple or quickly remedied situation.

The USACE capital stock value increased $4.9 billion on average each year from 1928 to 1982, representing a 13.1 percent average annual increase. From 1982 to 2011 the USACE capital stock value decreased by an average of 1.1 percent annually. Currently, USACE capital stock is estimated as being $191.4 billion or approximately what it was between 1964 and 1965. The current U.S. population of about 313 million is 65 percent greater than the estimated U.S. population in 1963 of 189.2 million.

- From 1982 to 2011 the USACE capital stock value decreased by an average of $2.5 billion each year. If the average annual rate of decline observed over the past 25 years persists, USACE capital stock will have a value of approximately half its peak value by the year 2044.
- Under the current study assumptions, over the next ten years $6.9 billion in annual investment would be required to sustain the capital stock value near its current level. Anything less will result in further decline over that time frame. To compare, the Construction General account appropriations for fiscal years 2009, 2010, and 2010 were $2.1 billion, $2.0 billion, and $1.6 billion respectively. These appropriations include spending for major rehabilitation.

5.5 Relationship of Findings to Performance of 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. Consistent with these findings, the U.S. Army Corps of Engineers Civil Works Program Five-Year Development Plan for FY 11-15 reported performance declines for key business programs dependent on capital stock including inland navigation, deep draft navigation, and hydropower production (USACE, 2011a 2012).

Specifically, Inland waterway segment unavailability hours has ranged from 27,000 hours to 43,000 between 2005 and 2010. Segment unavailability can have significant impacts. A recent Congressional Justification reported "a planned 18 day closure of the main chamber at Greenup Locks and Dam on the Ohio in 2003 was extended to 52 days when extensive deterioration of the miter gates was found. The lengthy closure cost shippers and carriers well over $40 million and several utilities came within days of having to shut down as coal supplies were exhausted (USACE, 2005)." Moreover, there have been six other Greenup closures during the last ten years with the most recent in 2010 (Maritime Professional, 2013).

Similar performance declines were reported for other business programs. Channel availability (center half of the channel) of high-use deep draft navigation ports has declined from 38 percent to 30 percent between 2005 and 2008. Hydropower facility forced outages between 2005 and 2010 ranged from 3.98% to 4.94%; These outage levels do not meet industry standards.

5.6 Data Limitations

Several places in this report make mention of particular 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 was unavailable but was estimated for the period 1936 through 1977 as described on page 9. 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, data allowing for the modeling of asset retirements over time was not available. These 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 presented an obstacle in developing PIM assumptions that reflect the actual behavior and characteristics of assets in the USACE portfolio. Assumptions applied to the 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 and the authors believe that these data would add significant value to the USACE capital stock estimate and should be considered when developing future updates.

A Monte Carlo simulation was performed for this study in an effort to account for uncertainty in the assumptions applied to the Navigation, Flood Risk Management, Multiple Purpose, and MR&T functional categories and has proven an informative tool. This tool has illuminated our understanding of the sensitivity of the capital stock value to the required PIM input parameters. This information points to the importance of establishing assumptions that closely reflect the actual operational behavior of USACE water resources infrastructure. It is also acknowledged that the availability of USACE-specific data that would allow for the aforementioned assumptions to be improved is the most desired approach.

5.7 Opportunities for Further Improvements in Estimating Capital Stock Value

This section provides a discussion of both the limitations encountered and the opportunities for improvement with regards to this most recent estimate of the USACE capital stock value. The authors of this report believe that addressing the issues outlined in this section would substantially improve both the process for updating future estimates as well as the quality of the estimates derived.

The PIM is a well-established methodology used to evaluate the productive capacity of a capital stock portfolio in the absence of disaggregated, "bottom up" data. 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:

5.7.1 Capital Data

Bulk capital data is available for each year covering the period of study from 1928 to the present day, but it is uncertain if the conventions used to define capital expenditures for each year are consistent over this time 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.

Similarly 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 included in the sum of capital expenditures reported each year, or conversely, to what extent were capital improvements not reported because they are accounted for in another funding stream. 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.

5.7.2 Service Life

The service life, in terms of the PIM, is the average age when the productive capacity of the original capital expenditure 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 assets 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 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.

5.7.3 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 used approximating 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.

5.7.4 Defining the Problem Statement

There remains one additional area that would alter, but improve, the credibility of this analysis. This is to better define the problem statement being addressed. An improved definition would alter the analysis because the flow of capital expenditures and the inventory being considered would have 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?[21] 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.

5.7.5 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. Given these emphases, 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.

[21] 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.

5.8 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 the PIM has been called into question due to the lack of detail it provides for focused portfolio management and recapitalization decision making. Issues regarding data availability and quality issues 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 the 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 the PIM is not well suited for detailed capital budgeting and investment portfolio management.

In order 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 (including public safety implications) and performance (including current and future benefits) of existing infrastructure in order 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 would likely benefit the capital stock estimation procedure.

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 (IPT) 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 IPT 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?
- Can historical expenditure data be disaggregated for analysis of particular asset groups?

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 efficiency deteriorates over time.

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

Beta (β) Factor - Represents the percentage change in an asset's productive efficiency when age moves by one unit.

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 efficiency.

Constant Dollars – An adjusted 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.

Dredging - A form of investment that sustains the capital stock value of navigation channels.

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 of time, or at the very least, for more than one accounting period.

Hyperbolic Age-Efficiency Pattern – A pattern of asset deterioration whereby an asset's productive efficiency declines at a slow rate in the first years of its service life and at increasingly faster rates towards the end of its service life.

Investment Expenditure- Dollars dedicated to creating capital (e.g., assets and/or infrastructure) with productive capacity. Includes construction, major rehabilitation, and dredging. USACE has accounted for major rehabilitation in both the construction and maintenance accounts.

Major Rehabilitation Expenditure - Dollars dedicated to sustaining the productive capacity of assets, effectively "restarting" an asset's service life by increasing reliability or efficiency, and thus considered a form of investment.

Mean Service Life – Mathematical average retirement age of a group of assets determined by the retirement pattern of said assets and includes all assets that are retired or discarded earlier in their service lives as well as all assets that continue to perform late into their service

Monte Carlo Simulation – A technique based on the use of random numbers and probability statistics to simulate physical and mathematical systems. A Monte Carlo simulation is commonly used to model phenomena with significant uncertainty in inputs. The Monte Carlo simulation process involves defining the domain of possible inputs, generating inputs randomly from a probability distribution over the domain, performing a computation based on the inputs, and aggregating the results.

Mortality Function – The pattern defining the rate of retirement of a group of assets of a particular type installed or constructed in a given year as related to the service life assumption (i.e., the determining factor in how long an asset survives before or after its service life). The mortality function is used in conjunction with the service life assumption to define the retirement profile of expenditures made to the capital stock.

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 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 – 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).

Productive Efficiency - An asset's ability to perform at its originally intended level of service.

Recapitalization – Funding intended restore capital value through for both new investment, major rehabilitation, and, in this paper, includes navigation dredging. In other literature, this "recapitalization" refers to adding financial resources to a firm or bank's balance sheet.

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

Retirement Profile – A set of assumptions required to model the retirement process of a group of assets over time. The service life and the mortality function define the retirement profile.

Service Life – The number of years that an asset is maintained in service.

Simultaneous Exit Mortality Function – 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.

Survival Function – Defines the fraction of a group of assets that is still in service over the lifetime of the longest-lived asset in the group. Related to retirement profile, the survival function is a component in determining the mean service life such that it illustrates the point in time whereby half of the assets within the group have retired and half remain in service. The survival function does not define a pattern of asset retirement; it depicts the pattern of retirement in order to define the mean service life and thus is a complimentary component to the mortality function.

Appendix B

Review Meeting Summary

The Institute for Water Resources (IWR) sponsored a meeting on September 20, 2012 at IWR attended by representatives from the Corps of Engineers, Bureau of Economic Analysis, Bureau of Labor Statistics, and the Office of the Secretary of the Army. (A list of participants is provided at the end of this appendix.) The purpose of the meeting was to provide an opportunity for those knowledgeable about and/or interested in capital stock analysis (CSA), and Value to the Nation (VTN) analysis with the opportunity to review and comment on the work performed. This appendix summarizes the views expressed by participants. The first section below presents general points about CSA and VTN during the meeting. The second section presents points made about CSA organized on the basis of several key discussion questions that participants were asked to think about. Similarly, the third section organizes points made about the VTN analysis on the basis of key discussion questions.

Summary of Key Points Made about CSA and VTN analyses:

The Corps of Engineers is moving to a system of portfolio management of its infrastructure that will be accomplished on a multi-objective, and watershed basis. Additionally, the Corps recognizes that Federal funding will be insufficient for proper operations and maintenance, as well as recapitalization of its portfolio, and that it will need to look at private sector investment sources of capital. Capital stock analysis and a focus on quantifying investment return take on extra importance for portfolio management in this investment climate.

CSA is useful in understanding the status of capital stock value as well as its fluctuations and decline over time (and what it would take to restore to the peak). This information can be used to help identify the magnitude of the future investments and the budgetary resources necessary to re-attain that peak. That peak level includes investments made in the past (e.g. multipurpose investments) which we may or may not want to do in the future.

There was a general agreement that the analyses presented were appropriate for programmatic justification and management purposes. However, it was also recognized that improvement in the quality and disaggregation of data used to inform the analyses for both the CSA and VTN should be made a priority.

Capital Stock Discussion Questions:

1. How does the CSA comport with generally accepted CSA methods, procedures, and assumptions?

- In general participants expressed the view that the use of a 60-year service life for the portfolio of Civil Works water resources assets was too short, and that a longer service life assumption should be used for all functional categories, citing particular projects that are still in service 70+ years after their installation.

- There was also a general recognition that analytically deriving service life estimates as well as deterioration rates for infrastructure is very difficult, and is a problem faced by everyone doing CSA using the Perpetual Inventory Method.

- Those from other agencies with experience in CSA expressed the view that the methodology and assumptions employed in the CSA were appropriate.
- Concern was expressed by some about the use of the Monte Carlo simulation for performing sensitivity analysis of results. It was suggested that showing CSA results at different service life ages would be more informative than the Monte Carlo approach presenting a distribution of outcomes at a 95 percent confidence interval.

2. Recognizing the intended use of the CSA (i.e. to inform understanding of current status of capital stock and investment issues) are there any recommendations for improving the quality/professional acceptability of the analysis and results presented?

- The general view expressed was that the greatest improvement in the current CSA could be made by improving the completeness and granularity of capital stock asset information, and also achieving greater disaggregation of information/assumptions about infrastructure service lives and deterioration rates for the different categories of Corps infrastructure.
- Participants generally concluded that the current CSA was suitable for "50,000 foot level" examination and discussions about portfolio management issues.

3. What are the most important areas for further follow-on development/improvement work of a more extensive nature? Are there lessons from other U.S. or international agencies concerned with CSA?

- Participants generally supported the recommendation made in the report for a focused work effort on improving the quality and disaggregation of capital stock data.

Value to the Nation Assessment/Return on Investment Discussion Questions:

1. How does the analysis comport with generally accepted Return on Investment (ROI) methods, procedures, and assumptions?

- Participants raised a number of questions about particular aspects of the Value to the Nation analysis:
    - The estimate of water supply benefits attributable to Corps projects is likely overstated because it was based on "finished water" prices instead of "raw water" prices.
    - The value of hydropower production obtained from Power Marketing Agency prices is likely overstated because the prices include distribution costs in the market prices.
    - There was some question that current inland navigation benefits presented in the report may overstate some benefits in that the Lower Mississippi River may have some capacity for navigation in a pre-project/ "without-project" condition.
    - Current Flood Damages Prevented estimates could be improved by using a 5-7 year moving average to smooth out yearly fluctuations in flood damages.

- Participants supported the caveat expressed in the presentation that the Deep Draft navigation estimate should be considered as a place-holder until a more thorough “with vs. without” analysis of coastal harbors is completed by IWR.

2. Recognizing the intended use of the VTN/ROI analysis (i.e. to inform understanding of recapitalization issues) are there any recommendations for improving the quality/professional acceptability of the analysis and results presented?

- In general, participants advocated continued work on improving data quality and completeness.
- More recognition should be paid to the importance of sunken capital in generating the stock of benefits profiled in the VTN analysis. The analysis should also clarify the distinction between the incremental analysis done in Corps benefit analyses and the ROI analysis presented in the VTN report.

3. What are the most important areas for further follow-on development/improvement work of a more extensive nature?

- Continued work on improving data quality and completeness.
- Future work should explore internal rate of return concepts for application in the ROI analysis.

Participant List

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Appendix C
Example Calculation Spreadsheet

This appendix describes an example capital stock calculation spreadsheet model developed to illustrate a simplified capital stock calculation using only five 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 spreadsheet used to illustrate the process.

STEP 1: Setting the input parameters

The "Assumptions" tab of the spreadsheet provides an interface that allows the user to set the PIM input parameters. **Figure C-1** below shows the input parameters used for this study outlined in red. Under the heading "Depreciation Assumptions", a drop-down menu allows the user to select from a variety of age-efficiency patterns (see Section 2.3.4 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 0.6 is set. Next the service life assumption is set to 60 years in cell C13.

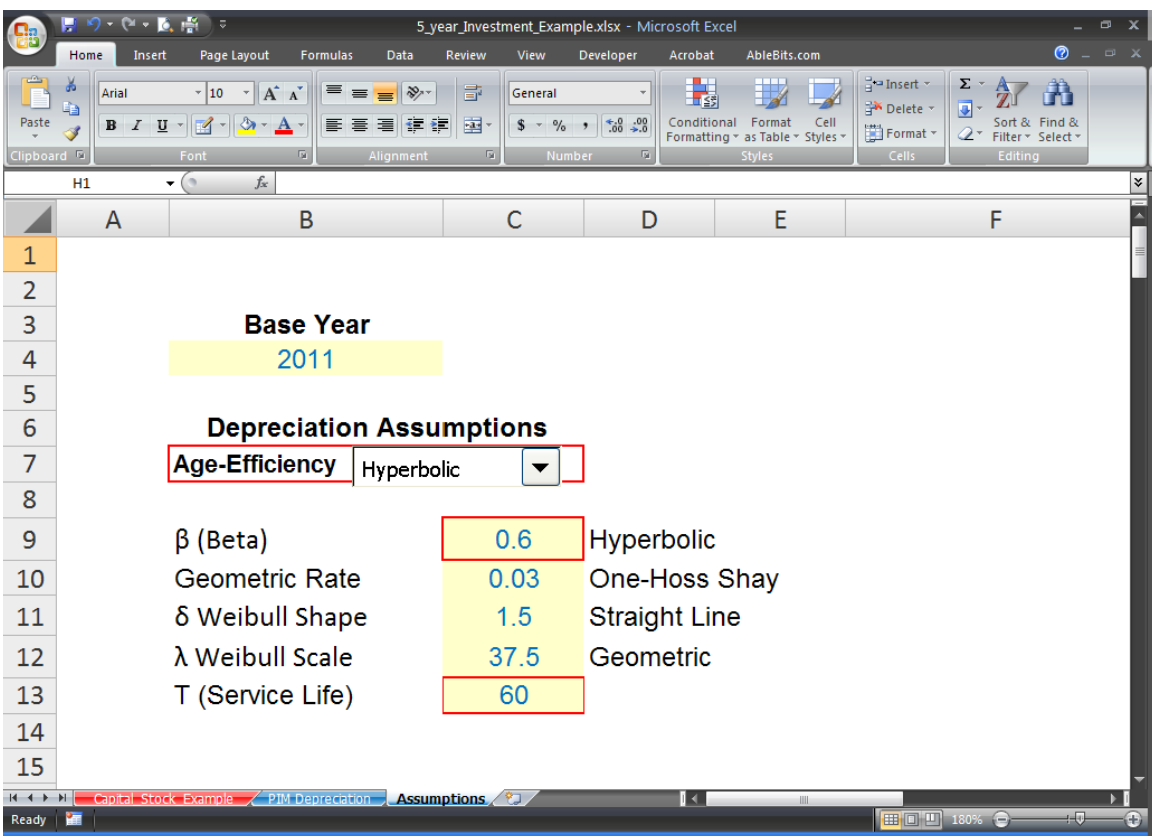
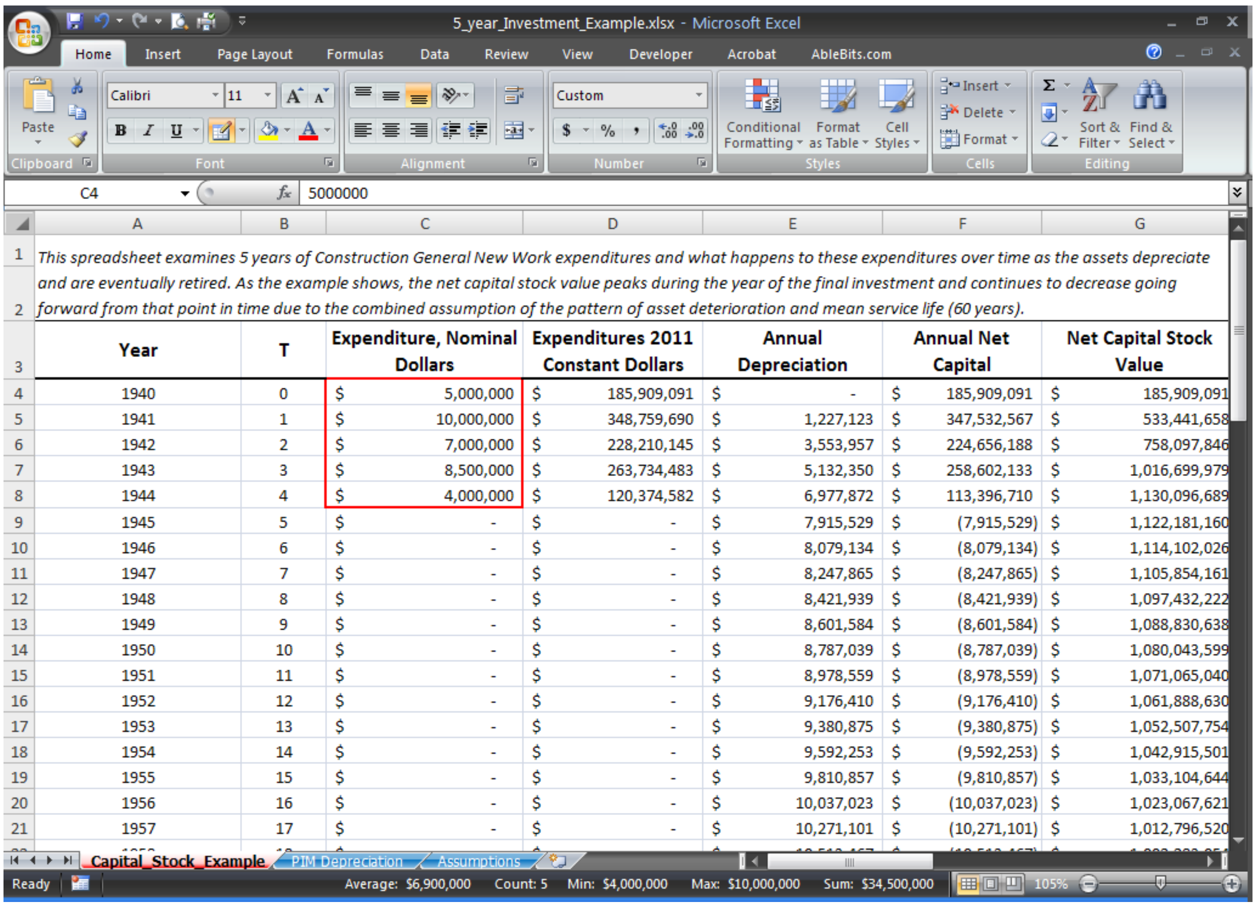


Figure C-1
Capital Stock Spreadsheet Model Assumptions

Step 2: Enter the annual expenditure amount

Within the "Capital Stock Example" tab, the user may enter annual expenditures into the spreadsheet. These expenditures 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 C-2** below, 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 using the Engineering News-Record Construction Cost Indices found in the "Assumptions" worksheet, cells B33:D141.



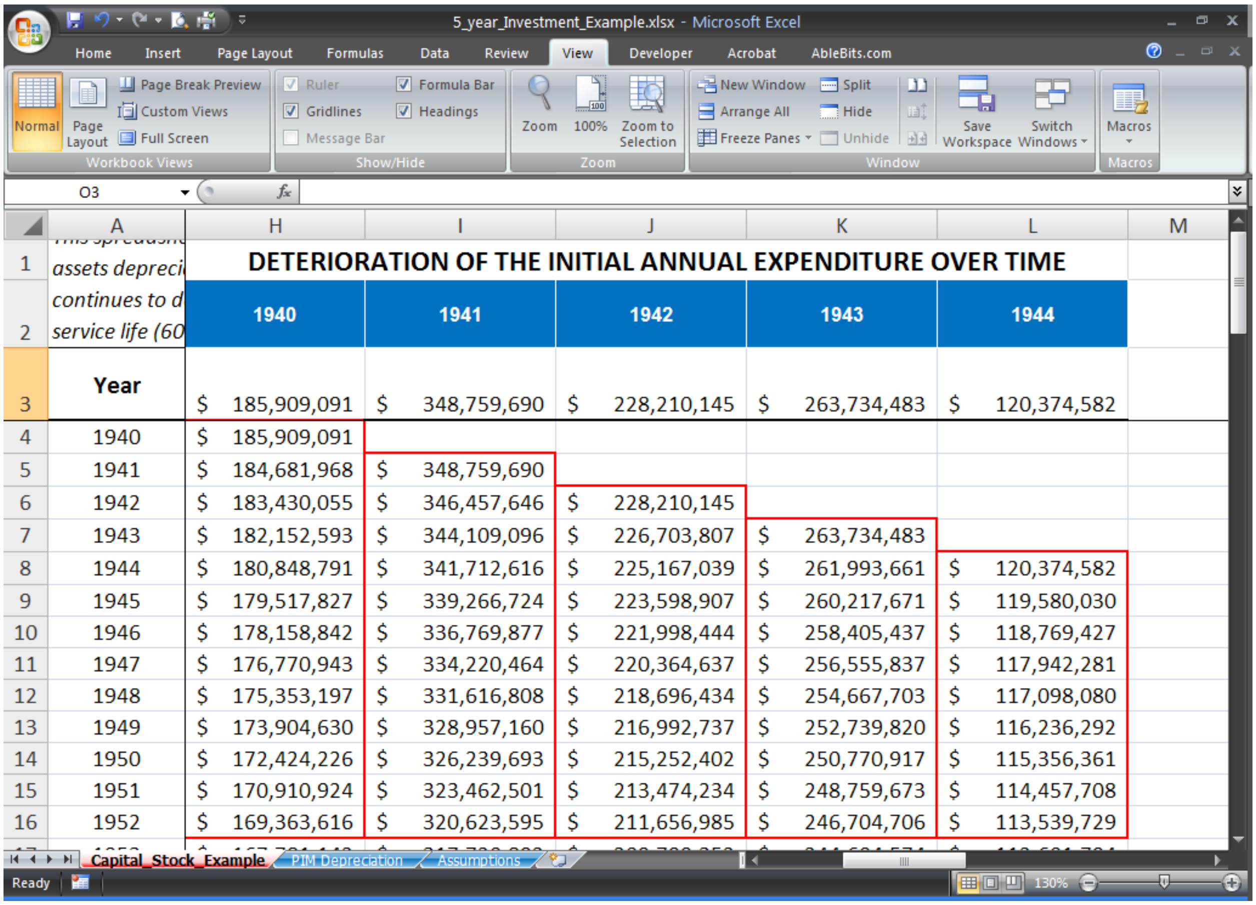
This spreadsheet examines 5 years of Construction General New Work expenditures and what happens to these expenditures over time as the assets depreciate and are eventually retired. As the example shows, the net capital stock value peaks during the year of the final investment and continues to decrease 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 C-2
Input Annual Construction General New Work Expenditure Data

Step 3: Deterioration of Initial Expenditures

Figure C-3 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 "PIM Depreciation" tab illustrates the asset depreciation pattern over time using the hyperbolic age-efficiency profile and a service life of 60 years. Note that the expenditures do not begin to deteriorate until the year after they were initially made.



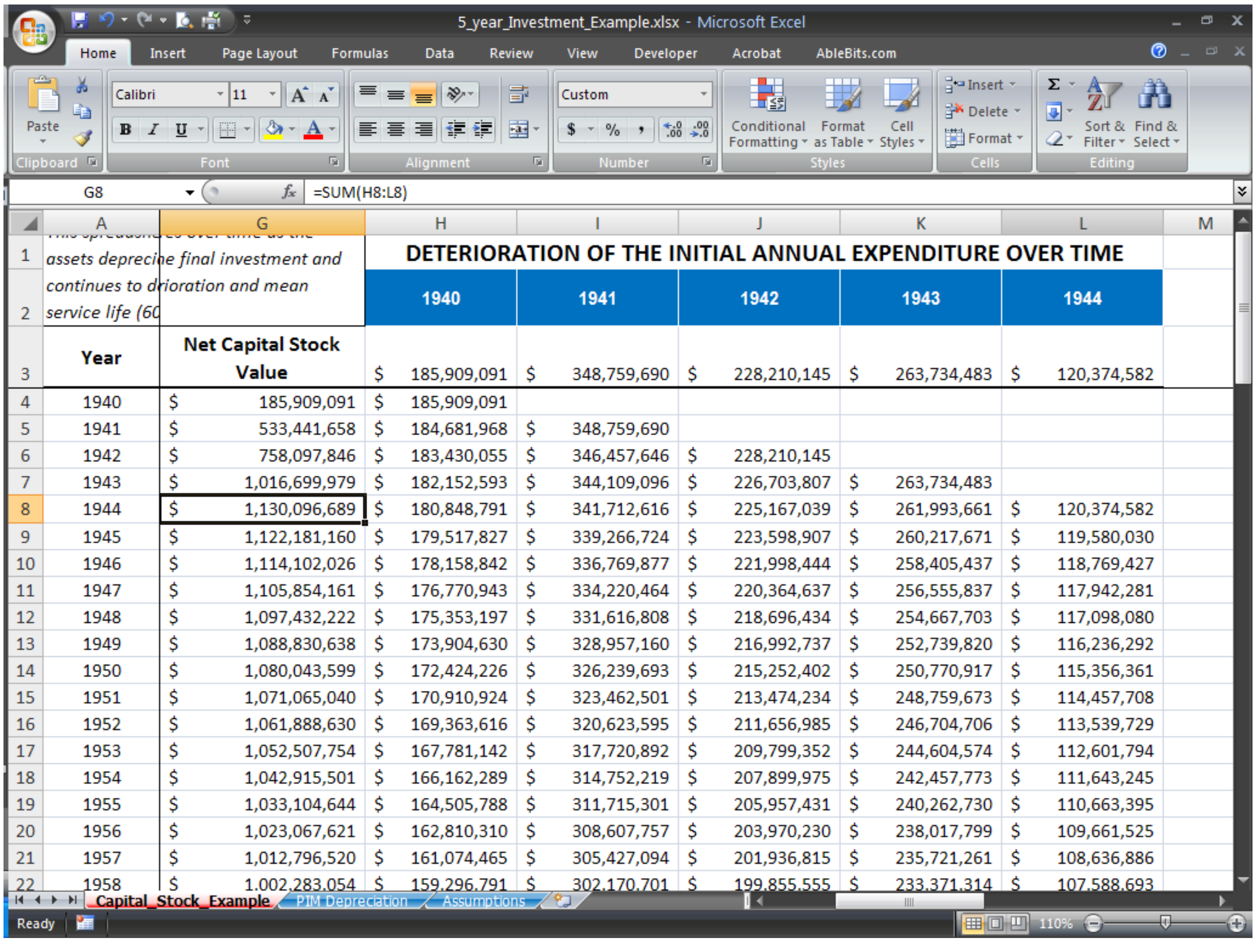
DETERIORATION OF THE INITIAL ANNUAL EXPENDITURE OVER TIME

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

Figure C-3
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 C-4**). 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 C-5**).



Year	Net Capital Stock Value	DETERIORATION OF THE INITIAL ANNUAL EXPENDITURE OVER TIME 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

Cigure C-4
Deriving the Net Capital Stock Value

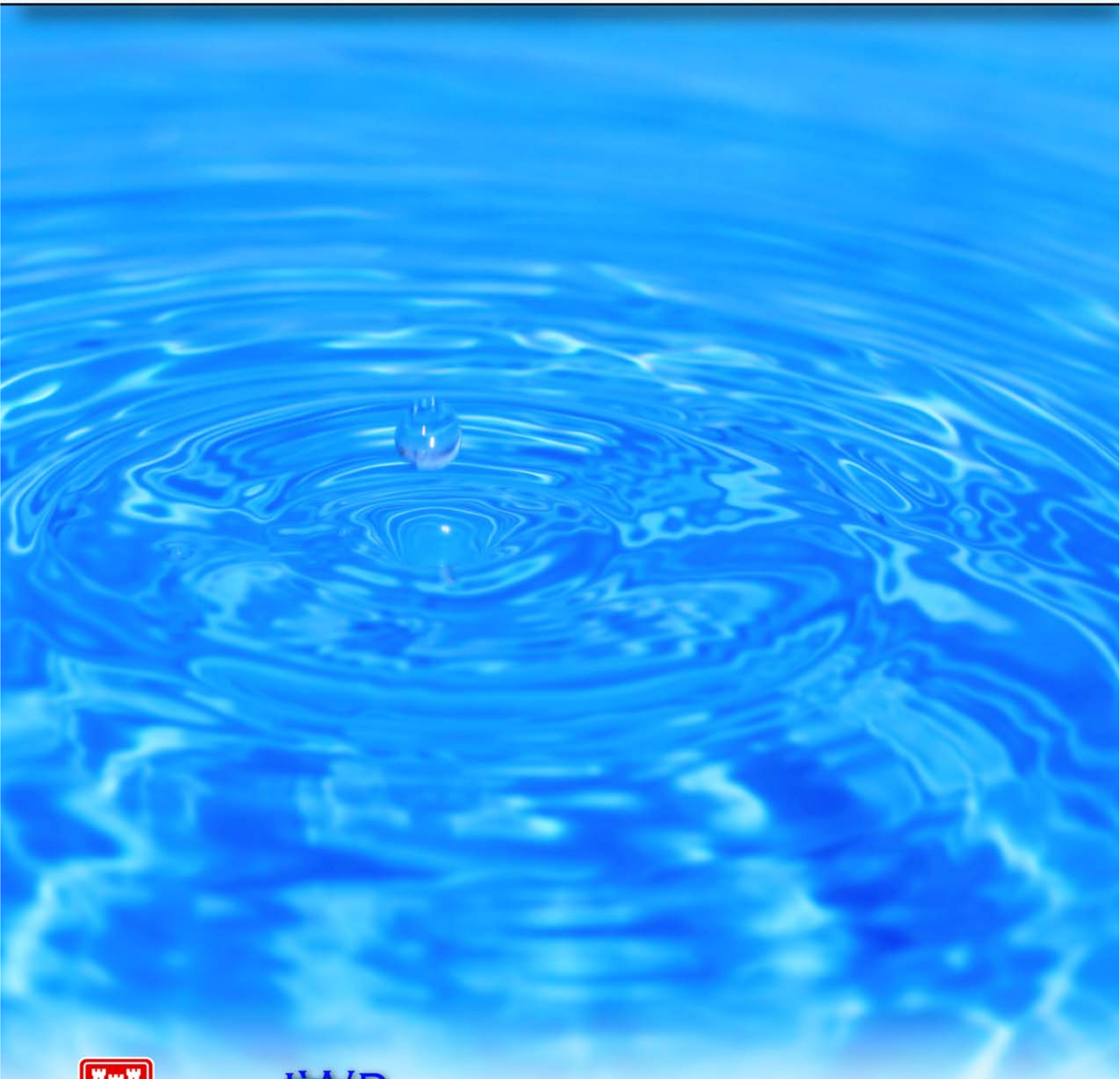
5_year_Investment_Example.xlsx - Microsoft Excel

G69 =SUM(H69:L69)

Row	A	G	H	I	J	K	L
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	$ -	$ -	$ -	$ -	$ -	$ -

Capital_Stock_Example | PIM Depreciation | Assumptions

Figure C-5
Capital Stock Value Declines to Zero 61 Years After the Final Expenditure is Input Into the Model



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