FRAMEWORK FOR AQUATIC ECOSYSTEM PROTECTION WITH APPLICATION TO TRANSPORTATION INFRASTRUCTURE AND IMPERILED SPECIES

by

WILLIAM HOWELL MATTISON II

(Under the Direction of Brian Bledsoe)

ABSTRACT

Rapid land conversion and variably-effectual regulations continue to put aquatic systems at risk of degradation. Management programs need to be adaptable and flexible in tailoring protection measures to the vulnerabilities of different types of waterbodies while balancing simplicity and complexity so as not to increase regulatory burdens. This thesis presents a general framework developed to streamline regulatory processes by tailoring protection measures to contextual susceptibilities of waterbodies across construction and post-construction phases of development and infrastructure projects. Application of the framework is based on an extensive analysis of scientific literature and various agencies' reports on potential stressors from transportation infrastructure projects and best available measures resulting in inventories, classifications, and predictive scientific assessment tools. Improved understanding of the applicability and effectiveness of protection measures enables increased flexibility, comprehensive planning, and a foundation for optimization of measures. The framework is applicable to several types of land conversion and infrastructure development projects.

INDEX WORDS: Protection measures, Aquatic systems, Infrastructure, Land development, Imperiled species, Transportation, Sediment, Stormwater, Toxicants, Directly connected impervious area, Best management practices

FRAMEWORK FOR AQUATIC ECOSYSTEM PROTECTION WITH APPLICATION TO TRANSPORTATION INFRASTRUCTURE AND IMPERILED SPECIES

by

WILLIAM HOWELL MATTISON

Bachelor of Science, University of Georgia, 2019

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2021

FRAMEWORK FOR AQUATIC ECOSYSTEM PROTECTION WITH APPLICATION TO TRANSPORTATION INFRASTRUCTURE AND IMPERILED SPECIES

by

WILLIAM HOWELL MATTISON II

Major Professor: Brian Bledsoe
Committee: Seth Wenger
Rhett Jackson

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
August 2021

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

OVERVIEW AND OBJECTIVES

Aquatic ecosystems are under increased pressures and stressors from land use change and development, expanding infrastructure, and population growth (Walsh et al. 2005, Wenger et al. 2009). Management of the effects of human activities on aquatic ecosystems through one-size-fits-all approaches that do not sufficiently account for differences in susceptibility among waterbodies can be ineffective and costly (Bledsoe et al. 2012). Separation and fragmentation of management programs can also exacerbate ineffectiveness and decrease flexibility (Freeman and Farber 2004, Karkkainen 2002) by splitting oversight of interconnected system components and various human activities among different jurisdictions or agencies. For example, nonpoint source pollution programs, which include numerous agencies responsible for different aspects of water quality management programs, have not been consistent in their oversight and effectiveness, with almost thirty percent of projects not achieving their objectives (GAO 2012).

The overarching goal of this research is to achieve improved ecological outcomes for aquatic systems affected by land development and infrastructure projects while streamlining regulatory processes to remove unnecessary burdens on project-proponents and reviewers. The following three specific objectives were identified for the thesis in support of this goal: 1) review the peer-reviewed and "gray" examining the influence of transportation infrastructure projects and activities on aquatic ecosystems with particular emphasis on conservation of aquatic imperiled species, 2) evaluate potential stressors, activities, and protection measures with respect to an ongoing case study involving state transportation and wildlife agencies with a focus on imperiled species, and 3) build on the literature review and case study to develop a general framework for tailoring the protection of aquatic ecosystems in the planning and development of land conversion and infrastructure projects.

This thesis is composed of four main parts: Chapter 2 – Literature Review of Construction-Phase Stressors and Protection Measures for Transportation Infrastructure Adjacent to Aquatic Systems, Chapter 3 – Framework for Aquatic Ecosystem Protection with Application to Transportation Infrastructure and Imperiled Species, Chapter 4 – Conclusions, and a supporting appendix. Chapter 2 is an extensive literature review that was conducted as part of my research involving transportation infrastructure and imperiled species. The purpose of the second chapter is to provide essential background and an example of the initial investments needed for the general framework. The literature review investigates stressors from construction-phase activities and the effectiveness of protection measures in reducing/eliminating those stressors on aquatic systems. An earlier version of this literature review was included in a final report to the Georgia Department of Transportation (GDOT; Nelson et al. 2021). The version that follows below has been updated to include additional references and explanations of the current state of sediment and non-sediment related protection measures. The third chapter of the thesis describes a novel, general framework for tailoring protection measures to the contextual susceptibility of waterbodies and their biota, and includes examples of the framework steps in the context of transportation infrastructure and imperiled species. The framework was developed to improve management planning effectiveness and flexibility across various types of land conversion and infrastructure development. The examples provided an opportunity to formalize, test, and revise the general framework and may also act as proof-of-concepts to others hoping to utilize the framework. Chapter 4 highlights the conclusions of the thesis. The appendix includes a table of 494 unique protection measures identified during an inventory of local, state, and federal agencies that highlights opportunities for improvement of current protection measures.

CHAPTER 2

LITERATURE REVIEW OF CONSTRUCTION-PHASE STRESSORS AND PROTECTION MEASURES FOR TRANSPORTATION INFRASTRUCTURE PROJECTS ADJACENT TO AQUATIC ECOSYSTEMS

Introduction

Transportation infrastructure (e.g., roads, parking lots, rail lines, airports, ports) is crucial to economic activity and covers large areas of the landscape, with almost nine million total lane-miles of roads spanning across the United States (USDOT 2020). Where transportation infrastructure intersects wetlands, streams, and rivers, bridges and culverts must be constructed to safely convey various flows of water and debris through the project. In the U.S. alone, there are over 617,000 highway bridges in use that vary from rural, single lane bridges to multilane and multilevel major river crossings (USDOT 2020). During the construction phase of these projects, pollutants, particularly sediments (Waters 1995), can be introduced at elevated levels to waterbodies, especially during and after rainfall events (Bernhardt and Palmer 2007, Cocchiglia et al. 2012, Wemple et al. 2018). Following the construction phase, stormwater infrastructure (e.g., ditches and drains) routes runoff with associated pollutants (e.g., heavy metals) directly from impervious surfaces to waterbodies (Bernhardt and Palmer 2007, Booth and Jackson 1997). The construction-phase of transportation infrastructure development required a synthesis of literature to expand our understanding of its activities, stressors, and effectiveness of associated protection measures.

The following literature review is primarily an in-depth analysis of current construction-phase activities for transportation infrastructure, associated stressors, and effectiveness of protection measures for attenuating the potential impacts of those associated stressors on aquatic systems. My primary contribution was conducting a review of the current state of knowledge on the effectiveness of non-sediment related protection measures and providing extensive support to my collaborator Dr. Tim Stephens in reviewing sediment-related protection measures. This literature review ultimately provides a foundation for recommendations and assessments of avoidance, minimization and mitigation measures/special provisions/best management practices (AMMs/SPs/BMPs) for the construction-phase of transportation infrastructure projects. The review enables effective programs, tailoring protection measures for infrastructure and development activities to the contextual susceptibility of waterbodies and their biota, to be predicated upon an understanding of potential exposure to stressors from these activities and how targeted combinations of measures can reduce/eliminate exposure.

Sediment is likely the most important construction-related stressor to freshwater organisms (Wood and Armitage 1997), but it is not the only one. Aquatic biota may be sensitive to multiple stressors (Ormerod et al. 2010, Segner et al. 2014), with some stressors having more effect than others for a particular species. For the purposes of this study, non-sediment stressors were classified as contaminants, physical contact, altered hydrology and connectivity, and noise (Nelson et al. 2021). This review is not intended to be exhaustive and there is always opportunity for new scientific literature to provide additional insights on stress-response relationships.

Sediment Related AMMs

Erosion and sedimentation from construction sites is intense with land disturbance activities (e.g., grubbing and grading) occurring at an extreme rate compared to other land use changes such as agriculture (NRCS 2000, Pudasaini et al. 2004). Soil erosion on construction sites typically occurs from splash erosion and rill/inter-rill erosion (Wood and Armitage 1997). Splash erosion occurs as the energy produced from a raindrop impacting the soil surface detaches and erodes the soil particles (Morrow et al. 2003). Rill (concentrated flow within rills) and inter-rill (shallow sheet flow) erosion occurs as the force of flowing water exceeds the resistive force of the soil and mobilizes particles (GSWCC 2016, NRCS 2008). Consequently, rainfall is a primary driver influencing erosion on construction sites, and rainfall intensity is more strongly correlated with soil erosion than total rainfall depth. This means short-duration, high-intensity storms can produce more soil erosion than a longer, less intense storm of equal rainfall depth (Nearing et al. 2005). Soils that have been disturbed by construction activities (e.g. earth moving) and left exposed are exceptionally susceptible to erosive forces (Benik et al. 2003, Faucette et al. 2006). Other pertinent factors that describe or influence the ratio of erosive forces relative to resistive forces, and thus erosion, are the soil type (i.e. its erodibility), topography that influences the erosive force of water, and BMPs that modify soil erodibility and/or hydraulic forces (EPA 2005).

Early studies investigating sediment production from areas undergoing construction revealed instream sediment concentrations that were orders of magnitude higher than in areas of natural and agricultural land use (Wolman and Schick 1967). Improvements in devices, regulation and implementation of erosion control practices in recent decades have reduced elevated sediment concentrations as a result of construction activities, but challenges remain.

In a questionnaire and field evaluation of Tennessee Department of Transportation (TDOT) construction sites, Schwartz and Hathaway (2018) found that only a few erosion and sediment (E&S) control measures are used in practice. Erosion control devices commonly applied by transportation agencies like TDOT include silt fence (with and without wire backing), rock check dams, enhanced rock check dams, and sediment tubes (i.e. wattles), catch basin protections, mulching/seeding, sediment filter bags, and temporary slope drains (Schwartz and Hathaway 2018). However, Schwartz and Hathaway (2018) also found that many of the devices listed in TDOT's drainage manual were never applied.

Separation of Exposed Soil from Waterbodies (Interception)

Erosion control devices can be generally classified by two types: those minimize exposed soil (i.e. source prevention), and those that attempt to separate exposed soil from waterbodies (i.e. interception). We discuss interception first.

Sediment barriers are an intercepting practice installed along the perimeter and within a construction site. They operate by ponding water long enough for suspended sediment to fall out of suspension and remain trapped behind the device. However, this requires a balance of capacity and flow through rate to prevent overtopping while ponding water long enough for suspended particles to settle (Whitman et al. 2019).

Common sediment barriers include but are not limited to silt fence, straw wattles (i.e. sediment tubes), compost filter socks, mulch berms, and others. Many of these practices and their standard details are listed in the Manual for Erosion and Sediment Control in Georgia (2016). Silt fence is the most commonly applied and studied sediment barrier ranging from field investigations, experimental studies, and small-scale materials testing in a laboratory setting

(Cooke et al. 2015). Burns and Troxel (2015) reviewed the relative frequency interception practices included in E&S control manuals across states, and silt fence was identified in 49 manuals with the next most frequent, straw or hay bales, identified in 22 manuals.

Silt fence is manufactured from a variety of woven and non-woven synthetic fabrics with variable mesh sizes which influences flow through rates. Variability in fabric type and mesh size is not an issue when larger soil particles are present (e.g., sand), as the mesh size of a silt fence should be smaller than the effective grain size of the soil. However, the efficiency of silt fence is greatly reduced as the representative grain diameter of soil becomes smaller relative to the mesh size (EPA 1993, Fisher and Jarrett 1984) and there are disparities between the efficiency of lab and field testing (Barrett et al. 1995, Chapman et al. 2014). For instance, GDOT standard specification 881.2.07 specifies Type A, B and C silt fence have an apparent opening size of 600 μm, while the diameter of a typical clay particle is 6 μm and smaller. It is important to consider the effective grain diameter of particles since some tend to coagulate producing a larger diameter particle and larger particles may cause clogging that would increase subsequent capturing of smaller particles.

In a full-scale experimental study, Whitman et al. (2019) found that turbidity measurements immediately downstream of various sediment barrier installations was greater than the upstream ponded water even though sediment retention rates were greater than 90% in some instances. Only one practice in their study decreased downstream turbidity, and it was an innovative approach that utilized flocculants in conjunction with layered wheat straw. While they did not specify the soil type, the high retention rates and increased turbidity for the silt fence practices suggests smaller particles were allowed to pass through. In contrast, Burns and Troxel (2015) observed up to a 93% reduction in turbidity downstream of silt fence installation, but their sampling locations are not clearly defined, and they simulate a 10-year, 6-hour event compared to the 2-year, 24-hour event by Whitman et al. (2019). A field test of silt-saver belted strand retention fence, which has a smaller apparent opening size and higher flow through rate than Type C silt fence, showed higher performance at reducing downstream TSS and turbidity than the Type C silt fence (Risse et al. 2008). The results of several experimental studies report variable performance rates of silt fence compared to alternative practices, such as compost filter socks and mulch berms. This is likely a result of the various testing methodologies, site conditions, and soils.

The results of several experimental studies report variable performance rates of silt fence compared to alternative practices, such as compost filter socks and mulch berms. This is likely a result of variation among experimental designs where soils, slopes, plot area, rainfall application and other factors are controlled. An evaluation of multiple sediment barriers using ASTM D351 indicated that Type A and Type C silt fence resulted in higher reductions in turbidity and TSS compared to mulch berms, compost socks, and straw bales (Burns and Troxel 2015). Straw bales had the lowest performance with a 91% reduction in TSS and a 49% reduction in turbidity.

In contrast, Faucette et al. (2009a) document a number of studies that report greater TSS and turbidity reductions using mulch filter berms and compost filter socks compared to silt fence (Demars et al. 2000, Faucette et al. 2005, Sadeghi 2006). However, Faucette et al. (2009a) evaluated TSS and turbidity reductions of straw bales, mulch filter berms, and compost filter socks under simulated rainfall, and reported removal efficiencies that are typically lower than those reported for silt fence under experimental conditions in additional studies (e.g., >90% TSS removal efficiency for (Burns and Troxel 2015, Risse et al. 2008, Whitman et al. 2018). There is a general consensus that straw bales should be avoided if other practices are available.

The variation in results among studies highlights the need to consider site-specific conditions when selecting and installing erosion control practices (Cooke et al. 2015).

The experimental study of Whitman et al. (2019) observed failure mechanisms in each device tested for a simulated 2-year, 24-hour storm. Three primary mechanisms were observed: overtopping of the device, undercutting of the device, and structural failure due to hydrostatic loading. Overtopping occurs when the capacity of the device is exceeded. For wattles and compost filter socks, this can occur simply due to the height of the device. For silt fence, clogging of the fabric pores can reduce the flow through rate causing excess water to pond behind the device and eventually overtop the structure. Undercutting of devices typically occurred due to installation methods and the stability of the interface between the installation and the soil. Structural failure due to hydrostatic loading could be caused by inadequate materials or reduced flow through rates that cause water to pond at depths greater than intended. For instance, structural failure of silt fence installed with hardwood stakes occurred in scenarios where a hardwood stake contained defects. Field evaluations of silt fence and other sediment barriers have indicated variable and quite low efficiencies of sediment removal in contrast to those reported in experimental studies (Barrett et al. 1998), which have been largely attributed to improper installation and maintenance neglect (Cooke et al. 2015).

The Manual for Erosion and Sediment Control in Georgia endorses the use of a static-slicing method to install silt fencing, based on an Environmental Protection Agency (EPA)-supported study in which the method performed as well as the highest-performing of three trenching methods tested, which typically required triple the time and effort (ASCE 2001). However Bugg et al. (2017), in a study for the Alabama Department of Transportation, demonstrated that one layer of trenched silt fencing method was less prone to failure than other methods that included slicing. A more recent experiment evaluated eight configurations of the Alabama Department of Transportation (ALDOT) standard wire-backed, nonwoven silt fence including the suggested method of Bugg et al. (2017) (Whitman et al. 2018). They found that altering the installation method to offset silt fence stakes 6” downslope of the backfill trench reduces the likelihood of undermining while increasing t-post weight and decreasing spacing reduces the likelihood of structural failure.

There is a general consensus that silt fence should not be placed in areas of concentrated flow, and this practice was removed from GDOT erosion control measures in 2014. However, a study found that, if maintained properly, silt fence could operate as intended in areas of concentrated flow (Cooke et al. 2015). However, this is still not recommended due to the frequent maintenance this would require and elevated likelihood of failure. While the majority of studies indicate that silt fence is one of the more effective interception practices, the variation highlights the need to consider site specific conditions when selecting and installing erosion control practices (Cooke et al. 2015).

Sediment basins have been frequently applied at transportation construction sites; however, this practice is infeasible in several scenarios due to topographic and spatial constraints. A number of studies have investigated the effectiveness sediment basins (Chapman et al. 2014, Line and White 2001), and found that, similar to silt fences, their effectiveness is variable depending on sediment texture (i.e. clay vs. sand). Since sediment basins rely on particles settling out of suspension, clay particles that have very slow settling velocities are not effectively retained. Enhancements to sediment basins include the use of flocculants to increase particle settling velocities, baffles to increase retention times, and skimmers so that water is drained from the surface. It is imperative to provide outlet protection for sediment basins to ensure that concentrated flow in these locations is not a source of sediment erosion.

Minimizing Exposed Soil

Hydroseeding is a type of planting (combining seed and mulch in a slurry) meant to stabilize disturbed soil of construction sites. This measure is popular due to its ability to be used on steep and unstable slopes, as well as difficult to reach areas, providing protection quickly to exposed soils (Harbor 1999). Typically, hydroseed is used in tandem with other measures such as silt fences and filter berms to enhance establishment of vegetation (Faucette et al. 2005). In field plot studies, Risse et al. (2005) observed hydroseed reducing runoff by allowing 43% to 47% more water to infiltrate compared to bare soil. The study also found that the hydroseed treatment resulted in significantly less total solid loss than exposed soil. Other hydroseeding trials have also observed reductions of soil erosion, even on steep cut and fill slopes, but remain aware that site characteristics can alter the measure's efficacy (Birt et al. 2007, Landis et al. 2005). Other types of source prevention practices have been found to be more effective than hydroseeding.

Mulch is another commonly applied stabilization measure to reduce soil erosion by reducing runoff rates and the energy associated with splash erosion. Experimental field studies have found that mulch can reduce erosion by greater than 90% compared to bare soil (McLaughlin 2002, Sidhu 2015), more than hydroseeding. Coverage rates and depths are the primary factors governing the effectiveness of mulch, and most guidance suggests 90% coverage rates (Meyer et al. 1970) to a depth of greater than 2 inches (Prosdocimi et al. 2016, Smets et al. 2008, Tyner et al. 2011). In a study using plots along highway right-of-ways in Louisiana, Bakr et al. (2012) found statistically significant differences in total suspended solids reduction between mulch thicknesses, with thicker mulch (10 cm) application resulting in improved reductions. However, mulch efficiencies in reducing soil erosion and runoff can be variable due to site characteristics (e.g., soil types) and precipitation patterns (e.g., rainfall intensity) (Lee et al. 2018). The addition of polyacrylamide flocculent (PAM) can further enhance the effectiveness of mulch (Soupir et al. 2004). Low levels of PAM added to mulch have been found to improve reductions of total suspended sediments and runoff, but conversely can increase both when applied at higher levels (e.g., twice the recommended rate) (Soupir et al. 2004). However, uncertainties remain as to the toxicity of PAM to aquatic organisms; the EPA (2005) recommends that cationic PAM should not be used due to its toxicity. On the other hand, anionic, non-oil based PAM products were quantitatively found to be safe for aquatic organisms, even at levels ten times more than those used for E&S measures (Weston et al. 2009).

Erosion control blankets/mats/geotextiles (usually made of natural and synthetic materials) have been found to be even more effective (Tyner et al. 2011), particularly a random-weave, high mass-per-area design instead of open- weave, low mass per area design (Álvarez-Mozos et al. 2014, Sutherland and Ziegler 2007). Erosion control blankets/mats/geotextiles reduce splash erosion and increase roughness to slow and impound overland flow, but their efficiencies can vary due to site variables (e.g., soil type, slope, etc.) (Rickson 2006). Application of compost erosion control blankets/mats promotes quicker vegetation establishment compared to traditional hydroseeding and mulching on construction sites with disturbed soils (Faucette et al. 2006). However, slope angles of the site and thickness of the blanket/mats can affect the performances of erosion control blankets; steeper slopes usually require thicker blankets/mats to reduce soil losses (Faucette et al. 2009b)

Non-Sediment Related Protection Measures

Contaminants

Heavy machinery and equipment used in close proximity to streams during construction increases the likelihood of spills and leaks releasing into waterbodies (Wheeler et al. 2005). A study was done that inventoried over 300 plant items to identify common factors behind spills. They found that equipment under the most stress, such as loaders and excavators, were most likely to experience failures. The failures usually occurred within the hydraulic systems of the equipment (Guerin 2014). Colorado Department of Transportation (CDOT) identified methods to deal with spills and leaks in their Erosion Control and Stormwater Quality Guide (2002). They called for an "ample supply of cleanup materials" to be present in maintenance areas and the use of absorbent materials to contain spills of hydraulic fluids, oils, gasoline, etc. Likewise, GDOT requires spill kits in maintenance areas. Another recommendation that CDOT made was the use of less hazardous and non-toxic petroleum products whenever possible. Mineral-based hydraulic oil is extremely toxic to aquatic organisms and does not break down as well as biodegradable alternatives, which contain high amounts of oxygen in their chemical structures and allow microbes and other organisms to break them down easily under aerobic conditions (Morledge and Jackson 2001).

Uncured concrete can be accidentally discharged into streams and riparian zones when work is done nearby (BPA 2016). Liquid concrete can be hazardous to aquatic organisms, admixtures contain chemicals that can be acutely and chronically toxic (Andersson and Strömvall 2001, Mocová et al. 2019). In addition, calcium and bicarbonate, found in concrete, have the potential to raise the pH of streams that have come in contact with uncured concrete (Andersson and Strömvall 2001, Kurda et al. 2018).

Treated materials such as treated wood can pose a significant hazard to aquatic organisms (Lebow et al. 2004). Treated wood can leach toxic chemicals such as chromium, arsenic, and copper that bypass stormwater BMPs designed to capture toxicants like them (Lebow et al. 2004). Cleaning and maintenance practices (e.g., power washing) can remove particles of treated materials and deposit them in the soil or water beneath a structure (Lebow et al. 2004). Lebow and Tippie (2001) presented guidelines to minimize any release of contaminants from wood treated with preservatives. They recommended reducing the amount of field fabrication of treated materials to prevent discharge of sawdust, drill shavings, and other construction debris. The paper states that materials that are observed having oily surfaces and/or "bleeding" after treatment are recommended not be used in environmentally sensitive areas. They also stated that treated materials should not be stored in areas of standing water or wet soils to prevent contaminants from easily entering adjacent waterbodies or soils. Oregon DOT also has similar measures ensuring that treated construction materials are handled and stored properly to avoid contact with surface waters.

Many pesticides and herbicides can be toxic to aquatic environments. Pesticides and herbicides can enter waterbodies through sorption to soil particles and subsequent transport or by aqueous transport in stormwater (Syverson and Bechmann 2004). With an experimental plot, Syverson and Bechmann (2004) found that vegetated buffer zones reduce the delivery of pesticides to streams. A review of measure effectiveness for pesticides from agriculture areas found that surface runoff and erosion of particles, with adsorbed pesticides, were the two most prominent sources (Reichenberger et al. 2007). The review also noted that the USDA suggests a 30 meter buffer width to trap soluble particles such as pesticides (Reichenberger et al. 2007). Arizona Department of Transportation outlined methods to reduce the amount of pesticides and herbicides that reach buffer zones or waterbodies. In their Herbicide Treatment Program on Bureau of Land Management Lands in Arizona (2015) , they prohibit broadcast spraying within designated buffer zones, call for the use of selective herbicides (labeled for use to the edge of bodies of water or with aquatic labelling) only, and allow only hand spray application.

Physical Contact/Altered Hydrology and Connectivity

The most direct cause of injury or mortality to aquatic organisms is physical contact: dropping of debris or crushing by heavy equipment, which is a particular threat to less mobile or sessile benthic organisms such as mussels (Cocchiglia et al. 2012). The greatest exposure likely occurs in the installation of piers, piles, jetties, and other in-stream structures.

Altering the hydrology and connectivity of waterbodies has been shown to cause adverse effects on aquatic biota. Poor bridge construction or placement can lead to habitat fragmentation. Piers that are incorrectly placed can cause scouring, bed instability, debris accumulation, and habitat fragmentation (Cocchiglia et al. 2012). Clear span bridges, that do not use piers or piles as supports, have been recommended in order to leave the natural bed and bank intact (Cocchiglia et al. 2012). Rip rap placement must also be considered to avoid unnecessary impacts; incorrect placement has been shown to change flow and sediment regimes (e.g., lowering velocities of stream lengths and increasing deposition of suspended sediments) that are crucial for maintaining natural channel morphology and habitat viability for aquatic organisms (Reid and Church 2015, Stein et al. 2013). Armoring along streambanks also requires the removal of natural vegetation where the material is placed, which can lead to degraded streambanks, disrupted natural sediment inputs, decreased woody debris input, and subsequent loss of water quality (Reid and Church 2015, Stein et al. 2013). Numerous armored channels were also observed exhibiting channel incision (Reid and Church 2015, Stein et al. 2013).

Noise

Blasting and the pressure waves associated with it have been linked to the mortality of aquatic organisms such as fish. Many techniques used by many departments of transportation and contractors that are aimed at reducing the overall mortality from these practices have been found ineffective. Repelling (or scare) charges, which are used to "scare" fish and other aquatic organisms away from blast sites, were observed by multiple agencies to contribute to fish mortality (Keevin 1998). One study showed that fish do not move far enough away from the main detonation zone to prevent mortality (Keevin and Hempen 1997). Bubble curtains reduce the explosive wave pressure from underwater blasting, but do not completely eliminate fish mortality outside of the curtains (Keevin 1998). The FWS, in a Florida Blasting Guidelines (2006) document, recommended stemming charges and using physical barriers to contain underwater blasting. Keevin (1998) found that physical barriers helped reduce the wave pressures. He also stated that stemming charges, which uses angular material such as crushed 403 rock to fill drill holes of charges, can significantly decrease the amount of blast energy leaving the hole. Pile driving activities are the main contributor to acute, anthropogenic sound disturbances associated with construction projects (Popper and Hastings 2009). They can cause fish mortality, damage to internal organs (e.g., swim bladders), and behavioral changes (Dahl et al. 2015, NOAA 2003, Popper and Hastings 2009). Some studies have even shown that aquatic species can exhibit both temporary and permanent hearing loss from these activities (Popper and Hastings 2009). Pile driving also causes fish to become overstimulated and thus more susceptible to predation (NOAA 2017, Popper and Hastings 2009). NOAA (2017) found that using vibratory hammers on piles, as opposed to traditional driven piles, does not impact fish as much by operating at different sound frequencies. Pile cushions can also reduce peak acoustic effects of driving piles while maintaining driving efficiency (Deng et al. 2016).

Synthesis

Modern field evaluations of erosion control effectiveness have shown a wide range of efficiencies (EPA 1993). Concise syntheses and evaluations on the effectiveness of construction-phase protection measures are lacking with large data gaps (e.g., efficiencies of measures attenuating non-sediment related stressors, field-based performances of measures, and cofferdams) in both peer-reviewed and 'gray' literature (Beighley et al. 2010). The majority of studies and experiments focus on only a few common types of measures (e.g., silt fences) and are conducted under optimal and idealized conditions in laboratory settings. Many fail to reflect the measures' performance in the field (Barrett et al. 1995, Barrett et al. 1998, Chapman et al. 2014) where numerous factors such as proper installation, maintenance, monitoring, soil type, topography, precipitation and hydrology can impact efficiencies (Barrett et al. 1995, Harbor 1999, Kaufman 2000). Certain measures can also be misapplied and inadvertently cause secondary impacts. For example, hydroseeding has been observed increasing total nitrogen levels of runoff when vegetation is not able to be established (Soupir et al. 2004). Nevertheless, despite these gaps in performance data and understanding, there is currently sufficient knowledge of processes and performance to begin improving how protection measures are employed, how their effectiveness is quantified. Over forty-eight protection measures were identified that were a mix of practice types such as activity restriction, source prevention, interception, and maintenance/monitoring (Nelson et al. 2021). Each of these measures were reasonable, efficacious options that have the opportunity to improve the effectiveness and consistency of protection measures across the U.S. through the transfer of best available practices among jurisdictions. At the same time, it is vital to obtain additional knowledge, data, and results (e.g., effectiveness under field conditions, operation and maintenance considerations, etc.) on protection measures' performances to improve guidelines and recommendations.

CHAPTER 3

FRAMEWORK FOR AQUATIC ECOSYSTEM PROTECTION WITH APPLICATION TO TRANSPORTATION INFRASTRUCTURE AND IMPERILED SPECIES[1]

[1] Mattison, W.H., Bledsoe, B.P., and Wenger, S.J. To be submitted to *Journal of American Water Resources Association*.

Abstract

Rapid land conversion, expanding infrastructure development, and growing populations continue degrade aquatic ecosystems. Regulatory processes and policies, typically driven by the Clean Water Act and Endangered Species Act in the U.S., aim to attenuate these stressors, but separation of jurisdictions and management programs between different local, state and federal agencies can hinder their effectiveness. Here we show how protection measures can be streamlined to reduce regulatory burdens and improve stewardship of natural resources. We developed a general framework that tailors management efforts to the contextual susceptibility of waterbodies by using scientific predictive assessments and optimizations among alternative protection measures across construction and post-construction phases of development. The general framework is applicable across different management scenarios and land development types, and is intended to improve stewardship of natural resources and reduce regulatory burdens. An application of the general framework is presented with an ongoing case study involving transportation infrastructure and imperiled species. Both the general framework and case study highlight how management and regulatory processes can be streamlined with substantial initial investments while maintaining cost-effectiveness for users and stakeholders, and achieving improved environmental outcomes for aquatic ecosystems in the future.

Introduction

Land use change and other development activities, population growth, and infrastructure needs are accelerating (ASCE 2017, Jacobson et al. 2001,United Nations 2019). Mega-regions are beginning to emerge like the Piedmont Atlantic megapolitan area spanning the cities of

Atlanta and Charlotte in the southeast U.S. This issue is also global in scope with the U.N. predicting that approximately 2.5 billion more people will be living in expanding cities and urban areas by 2050 (United Nations 2019). At the same time, there is a growing backlog of maintenance and repair costs in the U.S. for all types of infrastructure, and extensive plans for updating and expanding infrastructure which adds to the complexity of these challenges (ASCE 2017). For example, 20 percent of roadways have pavement in poor condition and a large number of bridges are approaching the end of their design life and require extensive rehabilitation or replacement. These issues result in a multitude of stressors on aquatic ecosystems including flow alteration, increased erosion, water pollution, and habitat degradation (Jacobson et al. 2001, Walsh et al. 2005, Wenger et al. 2009). With almost eighty percent of the U.S. population residing in metropolitan areas and the continuous expansion of development and infrastructure, associated stressors as well as tensions between regulatory processes and these activities will inevitably be increasing (Coles et al. 2012). .

Regulatory processes aimed at mitigating the effects of land use change and infrastructure development on aquatic systems in the U.S. are primarily driven by the Clean Water Act (CWA), which focuses on chemical, physical, and biological aspects of water quality, and the Endangered Species Act (ESA), which is concerned with impacts to imperiled species. Amendments to the Clean Water Act in 1987 expanded nonpoint source pollution management programs, which are administered across many agencies, both state and federal, as well as within sub-units of those agencies. For example, a state environmental agency may be in charge of overseeing stormwater during the post-construction phase, but for the construction phase, erosion and sediment control (ESC) programs may be administered by soil and water conservation commissions or state agricultural agencies. In the U.S., projects involving discharge of fill material fall under the jurisdiction of the U.S. Army Corps of Engineers (USACE) and the Environmental Protection Agency via Section 404 of the CWA. National and state environmental policy acts (NEPA/SEPA) are meant to unite these programs under one jurisdiction, but are not always applied to all projects and thus can be rendered ineffective (Mas 2003). Various management entities are concerned with different links in the causal chain and stages of impact to aquatic systems.

Water resources management seeks to find a balance in which regimes of both water quantity and quality maintain ecosystems and their benefits, despite competing water uses and flow regulation (Dyson et al. 2003). Ideally, management of water quality and aquatic life would be integrated across programs and policies and contextual to landscape, ecological, and hydrogeomorphic settings within which human activities occur (Freeman and Farber 2004, Poff et al. 2010). However, regulations must also strike a pragmatic balance between simplicity/predictability and customization to context. The need for contextual management is reflected in water quality standards like cold water vs. warm water aquatic life; however, these classifications often fail to reflect fundamental differences in relative susceptibility of different types of waterbodies within these broad classes (although there are some exceptions). With numerous agencies administering different components of water quality and imperiled species programs, fragmentation and compartmentalization inevitably occur, especially between construction and post-construction phases of a project (Esty 1999, Freeman and Farber 2004, Karkkainen 2002). Separating program components and dispersing them to different jurisdictions can also hinder flexibility in tailoring effective management strategies that achieve site-specific management goals and take local contexts into consideration. Given the current rates of urbanization and infrastructure expansion, these challenges and degradation are likely to increase over the next decades unless management programs innovate and adapt to these mounting pressures.

This confluence of land use change, costly regulatory processes, renewed infrastructure investment (Coles et al. 2012), and improved scientific understanding (Rankin 1995) motivate and set the stage for this study which seeks to improve tailoring of protective actions to the contextual susceptibility of aquatic systems while integrating and streamlining regulatory processes. Extensive conversations with various state DOTs, engineers, wildlife agencies, private consulting groups, and landscape designers have shown a widespread desire to avoid long, drawn-out regulatory processes with custom approaches for each individual project and instead begin to tailor management efforts more effectively to achieve improved ecological and economical outcomes. Specifically, we present a general framework for managing the effects of land conversion and infrastructure projects that explicitly addresses optimizing protection measures between construction and post-construction phases based on the contextual susceptibility of waterbodies. The framework is designed to balance the complexity of water resources management decisions with the need for greater efficiency, by effectively addressing the vulnerabilities of aquatic systems through cost-effective and practical management strategies that improve stewardship while alleviating regulatory burdens. It is applicable to a variety of management activities related to land conversion and infrastructure development. New land development and infrastructure projects are not the only opportunity for the framework to be applied; retrofits and expansions can also benefit from using the framework.

To streamline and improve integration of aquatic resource management and regulatory processes across construction and post-construction phases, we identified the following research objectives:

- Develop a framework for managing aquatic resources that supports more thorough evaluations of potential opportunities to optimize protection measures between construction and post-construction phases and focuses management activities where they will be most effective based on the contextual susceptibility of affected waterbodies.
- Using aspects of an ongoing transportation infrastructure case study, demonstrate application of the framework by comparing the effectiveness of protection measures in attenuating potential exposure to stressors in context of the sensitivity of a waterbody and its biota.

As described below, the framework is built upon multiple predictive scientific assessments that provide linkages along the causal chain between human activities, physical and biological effects, and biotic responses. This chapter of the thesis presents the steps of the general framework, and puts it into the context of transportation infrastructure development because it provides an opportunity for the comparisons due to two reasons: a vast array of avoidance, minimization, and mitigation measures (AMMs), special provisions (SPs) and best management practices (BMPs) are used across both phases and a large proportion of transportation infrastructure projects must already provide protection measures to meet both CWA and ESA requirements.

General Framework

The sections below describe the development of a general framework for tailoring protection measures to the contextual susceptibility of waterbodies and their biota in order to support cost-effective approaches to address the ecological impacts and stressors on aquatic ecosystems. The framework is intended to improve regulatory efficiency by streamlining management planning while striking a balance between stringent, one-size-fits-all management actions and time-consuming, complex consultation processes that are customized project by project.

The vision for the framework was developed by an interdisciplinary research team that understood the challenges and needs of management planning to effectively address stressors of aquatic systems from land conversion and development projects. As described below, several guiding principles informed its development.

First, an ideal framework is underpinned by the best available science incorporated within scientific predictive assessments (Bledsoe 2007, NRC 2001, Reckhow 1999) and is built to reflect key differences in the contextual susceptibility of waterbody types and organisms (Bledsoe et al. 2012, Montgomery and MacDonald 2002). In recent years, our knowledge has increased about how biota and waterbodies are differentially susceptible to various stressors associated with construction and post-construction phases of land development (e.g., (Cocchiglia et al. 2012, Logan 2007, Wenger et al. 2009). For example, a framework used for imperiled species protection should be tailored to the biota that are likely present and their sensitivities to the various types of exposure to guide the selection of management actions. The second guiding principle for the framework is the ability to span and integrate both the construction and post-construction phases of development. The ability to compare within, as well as among, projects is necessary to ensure protection measures are employed effectively. Third, the framework needs to determine both the sensitivity of waterbodies and their biota to stressors from types of land and infrastructure development and the potential exposure to the stressors from those project types. Combining sensitivity and exposure allows the framework to establish the susceptibility of a waterbody. Fourth, the framework should incorporate the best available protection measures for construction and post-constructions phases. It is important that thorough inventories of measures be taken and kept up-to-date to ensure that stressors can be reduced or eliminated effectively. Lastly, the framework needs to stay flexible, adaptable, and transparent (Bledsoe et al. 2012, Reckhow 1999) to operate effectively under the continually changing conditions of current and future land development with improved understanding of protection methods, waterbody sensitivities, and new kinds of projects. Flexibility is key in allowing project-proponents and stakeholders to select elements such as stressors, critical linkages, and initial protection measures that work best for their projects and sites. Within a framework, there should be built-in feedbacks that create opportunities for management efforts to be adaptable (e.g., optimizations of alternative protection measures among construction and post-construction phases). Adaptability should also apply to the initial investments with regular updates to up-front assessments such as literature reviews or inventories of protection measures as seen fit. Transparency is important so that project-proponents, stakeholders, and others are able to understand the steps taken in the framework, any predictive scientific assessments, how results/scores are generated, and ultimately the potential outcomes of a project.

The framework ultimately reflects the collective experience of an interdisciplinary team and their work on hundreds of CWA and ESA related development and infrastructure projects over the past three decades that involved numerous stakeholders and regulatory agencies across the United States. Through an iterative and heuristic process informed by extensive case studies, a general framework (Figure 1) shaped by the principles described above was developed for development and infrastructure projects to explicitly address protection measure optimizations between construction and post-construction phases based upon the contextual susceptibility of waterbodies to improve both measure effectiveness and regulatory efficiency. However, the framework was crafted so that it is relevant and applicable to a wide range of land conversion and infrastructure development projects and policy contexts. The main chart of framework schematic, depicting connected elements of the framework such as is assessments, processes, and tools (Figure 1), is presented as sequential steps (Figure 2) in the sections below; however, the full framework depicted in Figure 1 is iterative and includes multiple tools, layers of input, processes, and feedback loops.

Before the general framework can be implemented on a land development or infrastructure project, project-proponents and stakeholders must have a shared understanding and vision of what decision endpoints the framework is being applied to achieve. Defining the end user, the objective(s) of the specific project/program, project type(s) covered, and relevant requirements that must be met is a prerequisite before implementing the steps below.

Step 1a: Inventory and Classification of Protection Measures

A cornerstone of the proposed framework (Figure 1) is conducting a review of local, state, and federal agencies, management programs, and scientific literature on protection measures that could be employed on a project. The importance of creating an extensive and encompassing inventory of the best available protection measures is to ensure that activities occurring during land development will be mitigated to a level that is measurable, repeatable, and acceptable. This step also provides an opportunity to review current measures find areas of potential improvement. The inventory should be updated periodically to reflect the latest research on protection measures.

Classification of management actions facilitates matching individual protection measures to specific development activities. Classification also helps consolidate measures from various programs and manuals. For example, transportation projects come in many forms (e.g., highway development, bridge construction, culvert removal, etc.) and many state transportation agencies have numerous guides on protection measures addressing different types of projects. The Minnesota Department of Transportation has individual manuals for erosion control for local roads, alternative stormwater BMPs, BMPs for stormwater runoff in urban, suburban, and developing areas, best protection measures for meeting Department of Natural Resources (DNR) general public waters work permits, etc.

During an ongoing case study involving transportation infrastructure and imperiled species, a review, inventory, and classification of state and federal agencies' protection measures was performed and augmented with measures found in the literature. For the construction phase, thirteen different states' and agencies' guides, manuals, and programmatic biological assessments were reviewed: Federal Highways Administration, Florida Department of Transportation, Maine Department of Transportation (MDOT), Minnesota Department of Transportation, North Carolina Department of Transportation (NCDOT), North Dakota Department of Transportation, Nebraska Department of Transportation , National Marine Fisheries Service, Oregon Department of Transportation, Pennsylvania Department of Transportation, Tennessee Valley Authority, U.S. Army Corps of Engineers (USACE), and Washington Department of Transportation (WSDOT). These state and federal agencies were chosen for the inventory either due to their climate, region, and project types being similar to transportation agency's or their innovative programs and measures in the field. The review and inventory identified 494 unique protection measures that could be used on transportation infrastructure projects. Each measure was unique because redundancies or similar measures from other programs were consolidated into single measures. For example, MDOT, NCDOT, and

WSDOT all have measures calling for stabilization techniques (e.g., tarps, mulch, coir fibers, etc.) to be used on any disturbed soil, including temporary storage piles.

For the post-construction phase, the Georgia Stormwater Management Manual, GDOT Drainage Manual, and scientific literature were reviewed for stormwater BMPs, and fifteen new BMPs were identified during the inventory including site reforestation/revegetation and enhanced wet swales.

Step 1b: Inventory and Classification of Construction and Post-Construction Activities

Concurrent with the previous step, an inventory of specific activities associated with a type of land development or infrastructure replacement needs to be conducted for both the construction and post-construction phases. Key stressors that can result from potential construction and post-construction activities also need to be identified during this step of the framework. Key stressors may differ between phases; for example, the primary stressor of the construction phase of a project may be sediment while toxicants in stormwater runoff may be more important for the post-construction phase. The level of classification is up to stakeholders, but should be granular enough to accurately distinguish how stressors affecting aquatic systems differ among project types and activities. For example, a bridge replacement project should be classified in a way that all key stressors are identified such as sediment, contaminants (hydraulic fluid, oil spills, etc.) and physical contact from heavy equipment during the construction phase, and toxicants in stormwater runoff from new impervious areas from the post-construction phase. It is important to ensure that the activities have a classification system that is compatible and able to be cross-referenced to the protection measures from Step 1a to ensure that they can be linked for tailored management strategies. This will begin to help shape the rest of the framework going forward by highlighting what may impact aquatic biota or waterbodies.

Putting this step into the context of the case study, seventy-seven construction-related activities (e.g., grubbing, grading, etc.) and one post-construction-related activity (addition of directly connected impervious area (DCIA)) were identified that a transportation agency used on their routine project types. Input and collaboration with a federal wildlife agency was crucial in determining the impacts and stressors that would result from the activities. From this stakeholder engagement, as well as a review of scientific literature and inclusion of mandatory regulations from current policies, key stressors were chosen for each phase of a transportation infrastructure project. For the construction phase, the key stressor to aquatic systems was deemed to be sedimentation from adjacent hillside erosion, specifically bedded sediment (Palmer et al. 2014, Waters 1995). The review of literature and stakeholder engagement process also highlighted other stressors such as contaminants, physical contact, altered hydrology/connectivity, and noise caused by construction-related activities to be included as to provide a comprehensive view of the potential impacts the construction phase can have on aquatic systems. Toxicants such as zinc and other heavy metals found in stormwater runoff were determined to be the key stressor resulting from the post-construction phase. Runoff from impervious surfaces carrying pollutants such as heavy metals and hydrocarbons can have adverse impacts on biota even in small concentrations. Directly connected impervious surfaces, which are connected to streams through stormwater drainage networks and infrastructure, have been found to contribute substantially more runoff to adjacent waterbodies (Nelson et al. 2021). Zinc was chosen to be an indicator of toxicants and heavy metals being received from adjacent impervious surface cover based upon the available scientific literature and input from a federal wildlife agency. Post-construction impacts were based on this toxicity factor.

Each of these activities were classified by the type of potential impact it could have on biota and waterbodies (i.e., sediment, contaminants, physical contact, altered hydrology/connectivity, and noise). Classifying activities by their impacts allowed us to link transportation infrastructure activities with protection measures that could be employed to address the impacts.

Step 2: Identify Project-Relevant Protection Measures

Project-relevant protection measures are based on potential activities of land development or infrastructure replacement projects identified in the previous step. Project-relevant protection measures are broadly effective measures that can be justified for inclusion in all management plans and those that are automatically triggered by specific activities with a project type. They also include measures that are mandated by local, state or federal regulations no matter the context surrounding the project. However, they are not limited to these measures and can be additional practices required by the project-proponents or stakeholders for a variety of reasons. Project-relevant protection measures are identified by combining the inventory of measures (Step 1a) that are available with the construction and post-construction activities of a project (Step 1b). This set of standard protection measures be considered a "first draft" of a tailored management plan/strategy. It will be revised and refined in a later step based upon potential exposures to stressors and sensitivities of waterbodies and their biota.

For the transportation infrastructure and imperiled species case study, a total inventory of 494 unique AMMs (Appendix) were identified for the construction-phase during the review process. Many of these AMMs were already used by transportation agency (in some form or fashion);

however, additional protection measures were identified as improvements to existing measures or that were novel to them. It was extremely important that this was a stakeholder engagement process that solicited the input of all partners and agencies to ensure their confidence and approval of the measures.

Each of the 494 AMMs was assigned to one or more types of potential impacts it mitigates based on literature and expert judgment. It was then paired with the project type(s) to which it was applicable. Over 1,000 associations between AMMs and specific activities were made and thoroughly reviewed to remove any redundancies or errors. Project stakeholders reviewed the associations and offered expert opinions on the relationships. The refined associations were subsequently put into a database that and decision makers could access to automatically populate applicable AMMs based on the specific construction activities of a particular project (Nelson et al. 2021).

For the post-construction phase, fifteen stormwater BMPs were identified that would be feasible and effective to manage runoff from roadway projects. Fourteen of the BMPs were either included in the GSMM or GDOT Drainage Manual. In addition, a new riparian forest BMP was developed based on an extensive scientific literature review and collaboration with stakeholders to provide an efficient way to remove toxic heavy metals from stormwater runoff using natural processes associated with vegetation and soils (Nelson et al. 2021).

Step 3: Inventory of Biota Present in Waterbody(s)

In order to predict how a project can potentially affect a waterbody or waterbodies, it is important to identify the biological components of an aquatic system that are present (Pahl-Wostl

2007). Without this knowledge, it is impossible to conduct a thorough evaluation of the waterbody sensitivity to construction and post-construction stressors. Focal biota that needs to be identified during this step will depend on the regulatory framework, such as compliance for listed species of the ESA or indicators for the index of biotic integrity for the CWA. Inventories of biota can be performed using various methods (Kwak and Freeman 2010), including using state and federal lists/maps, conducting on-site surveys, and consulting with local wildlife agencies and experts. As mentioned above, the presence of habitat or potential for a waterbody to act as habitat for an aquatic species should also be considered during the inventory (Coles et al. 2012). Hydrologic connectivity of waterbodies plays an important role in this determination and should be analyzed during the initial assessment. For example, an aquatic species may not currently be present during an on-site survey, but if the waterbody is hydrologically connected to a reach one kilometer upstream where that species is found, the species should probably be included in the inventory.

Step 4: Synthesis of Species and Waterbodies Responses to Stressors

After creating an inventory of the biota present in the aquatic system, the general framework continues the initial assessment by asking project-proponents to establish linkages between waterbody and biotic responses to stressors from the land and infrastructure development projects (NRC 2001). A review and synthesis are crucial tools (Figure 1) that use the best available science to characterize the sensitivity of an aquatic system to the stressors from a project. It is important to note that there will be the possibility of missing data or literature on some individual species. In this case, supplementing data from biota with known sensitivities and the same functional traits (Poff and Allan 1995) may be necessary. The literature review should be updated periodically to include newer studies and data so that the best science is incorporated. Knowledge gaps identified during the review can guide future monitoring and data collection priorities.

Step 5: Sensitivity of Species to Construction and Post-Construction Stressors

Determining the sensitivity of aquatic species to a project's construction and post-construction stressors integrates the inventory of biota that are present in the waterbody with the synthesis of their responses to stressors from land development activities. Accurately conveying how each of the stressors impact biota and the receiving waterbodies of a project will cause management strategies to be more effective. For example, if a project occurring near protected freshwater bivalves or their habitat understands their sensitivity to siltation as a prerequisite for matching protection measures to the level of sensitivity and risk, effective erosion and control measures are be implemented to adequately protect the mussels. As with the previous steps, periodic updating of knowledge of biotic sensitivities as newer scientific literature becomes available is essential for science-based management. Causal linkages must be defined during this step to support development of predictive scientific assessment tools (which use a flexible mix of scientific literature, expert judgement, statistical and mechanistic models based on an understanding of system processes and causal linkages) as described in the section below.

Step 6: Estimation of Potential Stressors Caused by All Phases of a Project

To estimate the effect from the potential stressors of a project, it is necessary to develop predictive assessment tools that are rooted in recent scientific literature, and composed of a flexible mix of mechanistic and statistical models (Bledsoe 2007, Reckhow 1999) to ensure that likely impacts resulting from a particular project type and suite of protection measures is estimated accurately. The purpose of a tool is to create generalized model outputs that are applicable to multiple projects and project types without conducting individual literature reviews, and applying mechanistic and statistical models (or other methods) for each project. The project-proponents will determine what they need to quantify to accurately assess the impact a stressor will have on the biota/waterbody in question. The assessment of potential stressors for a project quantifies the risk from stressors by using a predictive assessment tool that combines both the sensitivity of the waterbody and its biota and the potential exposure to stressors from a project's activities (both determined in previous steps; Figure 1). For example, on a bridge construction project, a spreadsheet tool calculating the amount of impervious area added by the project is combined with sensitivities of species present (linking habitat degradation to incremental increases in percentage impervious area) to determine the impact of the post-construction phase of the project. Generalized outputs from predictive scientific assessment tools can be used as inputs for a scoring or accounting system using a type of risk currency. The system has to be able to vary in complexity depending on the situation; some instances may require subscores to be developed to improve understanding and transparency and later combined for an overall score (e.g., Nelson et al. 2021).

For the transportation infrastructure and imperiled species case study, an extensive literature review was completed to assess the potential effects of construction (Chapter 1) and post-construction activities. Input was solicited from project-proponents on the potential stressors of construction activities that were identified during the inventory processes and subsequent literature reviews.

Using the information from recent literature and expert opinions, predictive scientific assessments were developed to quantify the impact of both phases of development without protection measures. For the construction phase, a sedimentation-model combining mechanistic and empirical elements based on the Revised Universal Soil Loss Equation (RUSLE) (Wachal et al. 2009) was developed to estimate the loading and accumulation of bedded sediment and how that sediment would interact with the waterbody and habitat of aquatic biota via potential storage and flushing potential (e.g., specific stream power). Other construction phase stressors were identified such as contaminants, direct impacts, and altered hydrology, but there was insufficient literature to quantify the extent of their impact on aquatic biota. However, literature and expert judgment was used to make qualitative estimates of their potential impact on aquatic biota to guide decisions on measures effectively mitigating them. The post-construction phase impacts were quantified using a toxicant loading-model determining the amount of toxicity a waterbody was receiving from stormwater runoff via the total amount of DCIA added by a project (Nelson et al. 2021).

Two types of predictive scientific assessment tools were created to generalize outputs from these intermediate complexity models that include a flexible mix of mechanistic processes and empirical relationships from the literature, per the general framework. The first tool was built this way and provided this type of information that was essential to effectively apply the sedimentation-model to the construction phase of a project. It required six inputs: the county where the project was taking place, aquatic organisms present, site descriptors (e.g., limits of disturbance, terrain length and slope, soil type, and drainage area), project type, and appropriate construction activities in order to calculate the potential impact of sediment on receiving waterbodies. The second tool was also built the same way and provides essential information to the toxicant-loading model to estimate the potential impact of the post-construction phase of a project. However, it only required one input, the total amount of DCIA added, to estimate the potential impact of the post-construction phase from toxicity via stormwater runoff. The output from these tools provide inputs for the scoring system, made up of subscores and overall scores, used to quantify and compare potential impacts of stressors from both phases of a project. Processes represented in the models described above occur in the background of the tools with enough transparency for users to understand the logical flow of tool inputs and outputs. The tools allow for a simple, yet efficient format only requiring a few inputs for each individual project that described general project, site, and waterbody characteristics; but the format was still based in science, repeatable, applicable to all projects, adaptable with updates of new knowledge, and supports cost-effective decisions (Nelson et al. 2021).

Step 7: Assessment of Probable Effectiveness of Protection Measures Employed

Assessing the probable effectiveness of management strategies follows similar steps as the assessment of potential stressors. In this step, a predictive assessment tool is needed to evaluate the feasibility and likely effectiveness of different types and combinations of protection measures. Understanding the probable effectiveness of a measure is paramount; however, the feasibility of a measure based on a project's characteristics and activities, as well as the perceptions and willingness of project-proponents to utilize it, is also very important. Project-proponents also have the option to consider feasibility during step 2, but feasibility must not limit the scope of that initial draft as it could cause projects to have less flexibility with their options and combinations of protection measures. Feasibility can also change from project to project. A variety of factors such as regional rainfall patterns, site characteristics, critical stressors, and processes (e.g., evapotranspiration, infiltration, etc.) simulated by protection measures can dictate whether a strategy can be used successfully (Ackerman and Stein 2008). The effectiveness of protection measures can also mean different things (e.g., removal efficiency, load reduction, etc.) and quantification is up to the project-proponents and other stakeholders. Data on measure effectiveness may be sparse or unavailable in the literature. It is important that project-proponents and stakeholders define the level of accuracy needed for decision-making, and that this policy decision is informed by the likelihood of failure and potential consequences associated resulting from failure of AMMs/SPs/BMPs.

Step 8: Integration of Applicable Protection Measures

In step 2 of the general framework, a set of standard protection measures, that is warranted on all projects, was identified. However, the current step represents an opportunity for going above and beyond these measures to achieve improved environmental outcomes while maintaining cost effectiveness. Integration of applicable protection measures combines the previous assessments on potential stressors caused by all phases of a project and probable effectiveness of protection measures employed (Figure 1), so that project-proponents and stakeholders can select measures that will effectively prevent or mitigate both construction and post-construction stressors. The mixture of protection measures selected should comprise a more tailored management strategy compared to the "first draft" developed in step 2. It addresses key stressors from the project and their potential impacts on waterbodies and aquatic biota. This step of the framework can be revisited via a built-in feedback loop (Figure 3) for optimizing protection between construction and post-construction phases to achieve an improved ecological and economical outcome for a project.

For the case study involving transportation infrastructure and imperiled species, the previous two steps (Step 7 & 8) were combined to select additional applicable protection measures spanning both phases. For the construction phase protection measures, an effectiveness rating was determined based upon their type of protection (activity restriction, source prevention, interception, and maintenance & monitoring) and efficiencies provided by recent literature and expert opinions. The literature and expert judgment asserted that activity restrictions were the most efficient protection type, followed by source prevention, interception, and monitoring and maintenance. Nine decisions trees were developed for each protection type that used a series of logical questions assigning a protection level being achieved by a set of measures selected for a project. Decision trees were chosen in order for BMP protection levels to be as transparent as possible with the consistent logic so that project-proponents can understand how a particular efficiency or score is determined. Each decision tree aimed to provide multiple pathways to achieve a desired level of protection to give project-proponents and decision makers more flexibility, but also required certain protection measures to be employed on any project. Decision trees and BMP levels were also developed for non-sediment impacts (e.g., contaminants, physical contact, altered hydrology/connectivity and noise), but species sensitivity dictated the level of protection needed to be achieved by the combined AMMs. For example, if a species was extremely sensitive to noise impacts, more protective AMMs would be required to reduce the risk of noise exposure during the project (Nelson et al. 2021). Timing restrictions can also be used to reduce potential physical contact impacts of a project to zero such as restricting in-stream work that may crush benthic organisms during their reproduction season. An overall rating was given to the BMP level of a project (e.g., standard, advanced, advanced-high, high, or very high) based on a combination of measures used (Figure 4). As stated, a minimum level of erosion and sedimentation BMPs were required for every project, regardless of any contextual susceptibility of the waterbody or site characteristics. Additional E&S BMPs that increase redundancy or provide additional protection beyond the base level of implementation, reduce the probability and likely severity of a major failure of erosion control, represented by an exceedance of a design event (e.g., 2-year, 24-hour storm event) that triggers a large input of fine sediment that buries the bed substrate in a receiving waterbody (Nelson et al. 2021).

For the post-construction phase, toxicity reductions of toxicants such as heavy metals were quantified by using the GSWMM, GDOT Drainage Manual, and recent literature (e.g., (Clary et al. 2017)) for each stormwater BMP type identified previously. Reducing the impact of DCIA with BMPs involves disconnecting impervious surfaces from adjacent waterbodies. For example, a project can treat DCIA by filtering stormwater runoff from a parking lot through a bioretention basin before discharging it into the drainage network (Nelson et al. 2021). Toxicity reduction values (TR%) were developed for each BMP with performance functions using a design storm depth (a rain depth representing a volume of runoff from a design storm event being attenuated by the BMP). Treatment trains or combinations of individual stormwater BMPs were encouraged to be used to achieve better toxicity reduction values on projects. The equation for the TR% of stormwater BMP treatment trains was developed using empirical knowledge of stormwater BMPs processes, past experiences, and guidance from the scientific literature; it was refined and finalized after extensive conversations, reiterations, and input from a UGA stormwater research team:

$TR\%$ for $BMP_{TREATMENTTRAIN} = ((TR_1\%$ for $BMP_1) + (1 - TR_1\%$ for $BMP_1)(TR_2\%$ for $BMP_2))*\ldots((TR_{n-1}\%$ for $BMP_{n-1}) + (1 - TR_{n-1}\%$ for $BMP_{n-1})*(TR_n$ for $BMP_n))$.

The total amount of DCIA added by a project was reduced to a new Net Discounted DCIA by multiplying the total amount of DCIA added by the TR% factor. Previous DCIA can also be treated through retrofits to further reduced the Net Discounted DCIA.

To simplify and streamline these processes, the extensive decision trees, AMMs/SPs/BMPs efficiencies, regressions, and equations were integrated into the predictive scientific assessment tools referenced in the previous steps to produce effect scores reflecting selected protection measures in both phases of development.

Step 9: Contextual Susceptibility of Waterbody

For this step in the framework, a culmination of multiple steps must be integrated (Figure 1). The sensitivity of the waterbody and its biota determined in step 5 is combined with the total potential exposure to key stressors of construction and post-construction activities in step 6. Then, using selected protection measures and their efficiencies from steps 7 and 8, the amount of attenuation of the total potential exposure determined gives a net potential exposure from key stressors. The contextual susceptibility of a waterbody is defined as the sensitivity of a waterbody and its biota integrated with the net potential exposure to stressors from both phases of a project. Contextual susceptibility can also be dictated by regulations. For example, a waterbody's susceptibility could be based on its ability to meet a designated use per the CWA or imperiled species present per the ESA. After the contextual susceptibility has been determined, project-proponents and stakeholders need to use it in their assessment of whether the goals and objectives for a project were met. Were the stressors prevented/mitigated effectively? Did the project stay within budget? These are just a few examples of what may be important for a project, its stakeholders, the waterbody/biota, and the public. If they have not been reached, then a reevaluation process and optimizations need to be considered.

Step 10: Optimizing Construction and Post-Construction Protection Measures

A key component of the general framework that highlights flexibility and adaptability is the potential for optimizing protection measures across different phases of a project based on the contextual susceptibilities of receiving waterbodies and their biota. Optimizations require some type of risk currency to allow the framework to consider and evaluate alternative protection measures spanning phases of development, waterbodies, stressors, biota, etc. It can be a continuous variable (e.g., function assessment scores by USACE using the Hydrogeomorphic Approach, flow-ecology relationships in Bestgen et al. (2020), Poff et al. (2010)) or categorical (e.g., low, medium, high, very high classifications in Bledsoe et al. (2012)). A type of accounting system using a set currency such as an effect score is recommended to simplify and formalize this process and maintain transparency for all project-proponents. For a project, both the short term and long-term impacts of key stressors must be considered to explore effective alternative protection measures (Angermeier et al. 2004, Wheeler et al. 2005). If project proponents and stakeholders decide the impact of a project, based upon the contextual susceptibility from step 9, is not acceptable (failing to meet their goals, objectives, and standards), they can evaluate and consider alternative combinations of measures that provide the target level of protection across the construction and post-construction planning periods. However, regulations and policies may impose a minimum/standard level of project for every project (see step 2). Step 10 is broken down into two parts outlined in Figure 3 that are necessarily iterative of previous steps. First, both the potential exposure from the project's activities and the sensitivity of the aquatic biota/waterbody are reassessed to ensure that the correct protection measures are matched with the vulnerability of the biota/waterbody in question. Second, optimization of protection measures across the construction and post-construction phases can be considered so that the resulting set of protection measures and overall plan should be commensurate with vulnerabilities identified across both phases during the reassessment. For example, if

it is determined during a reassessment of a bridge project, that the biota present are extremely sensitive to sediment deposition, but insensitive to anticipated concentrations stormwater toxicants, the management plan can be adjusted to bolster and enhance ESC measures providing flexibility on the selection of stormwater BMPs for toxicant removal to achieve improved ecological outcomes and more cost-effective management action. Project-proponents and stakeholders need to decide whether the optimization and new management plan will meet the goals, objectives, and standards of the project (step 10) if it is implemented. If the answer is yes, the management plan can move forward towards approval; otherwise, another iteration of the steps above is completed until the overall package of protection measures across both phases results in an acceptable level of probable effects.

The overall impact of a project is defined as the acceptable level of probable effects caused by a project on receiving waterbodies and biota. ‘Acceptable’ is established and guided by a multitude of objectives, goals, standards, regulations, etc. set by the project-proponents. Stakeholder input may be used to set many of these (e.g., a conservation group wanting to protect the habitat of a specific game species), but others will be mandated by regulators such as local, state, and federal agencies (e.g., the USFWS or National Oceanic and Atmospheric Agency (NOAA) ensuring the protection of an imperiled species under the ESA). The ultimate goal is improved stewardship of natural resources through adaptive management, decision support-tools and a transparent, science-based process that integrates context and both phases of development to streamline regulatory processes across projects

Discussion

The framework provides a practical and cost-effective approach for management planning that improves protection measure effectiveness, regulatory efficiency, and stewardship of natural resources by addressing key stressors and waterbody sensitivities across construction and post-construction phases with optimizations of alternative combinations of measures. The examples from the ongoing case study serve as proof-of-concepts for the framework and presents functional applications in the context of transportation infrastructure and imperiled species.

With increasing stressors placed on aquatic ecosystems by population growth and rapid land development, there is a need for a more adaptive approach to water resources management (NRC 2001, Poff et al. 2010). The general framework uses adaptive implementation but provide greater flexibility, especially upfront, by allowing project-proponents the ability to choose key stressors, critical linkages within an aquatic system, and protection measures that are most appropriate for the biota, waterbodies, and their project types. The framework is focused on protective efforts using effective management measures (e.g., protecting designated uses like aquatic life under the CWA), not custom restoration practices (e.g., NRC (2001)). The framework, as recommended by Palmer et al. (2014) and numerous stream restoration papers, looks outside of channels and into the surrounding watershed to reduce or remove sources of stressors on aquatic systems. Predictive scientific assessments and initial investments of intermediate complexity (e.g., inventories, literature reviews, etc.) are vital aspects of the framework and case study to help streamline management planning. Previous research stresses the importance of these assessments and the initial investments to build solid foundations in the best available science, mix of mechanistic and statistical models, and expertise (Bledsoe et al. 2012, NRC 2001, Reckhow 1999). The general framework also highlights the need to put management into specific settings, whether those settings are dictated by regulations, imperiled species, ecosystem services, hydrogeomorphology, etc. Other papers use this paradigm of context-driven management for urban stream degradation and prioritization of stream restoration/protection (Beck et al. 2019, Bledsoe et al. 2012, Vietz et al. 2016).

Numerous offset and water quality trading programs have been used to mitigate stressors within or across watershed boundaries (Feldman et al. 2015). The framework and case study use a similar program, but one that stays within a project and promotes optimizations, instead of credit-based system, among alternative protection measures across both phases of development. The literature has also begun to address how the effectiveness of one-size-fits-all management approaches is inconsistent by either being under-protective and failing to mitigate stressors or overprotective and wasting resources; they provide frameworks and tools that address how the physical conditions of waterbodies are influenced by land development activities (Bledsoe 2007, Bledsoe et al. 2007, Bledsoe et al. 2012, Booth and Bledsoe 2009, Murphy 2020).

The examples from an ongoing case study are proof of concepts showing that the framework is tractable and feasible despite the initial investment of time and effort. The examples provided the opportunity for expansion of an existing list of protection measures through thorough evaluations of other local, state, and federal agencies around the country, and inclusion of additional measures using the best available information on effectiveness (e.g., a riparian forest BMP), all while adding more flexibility to improve stewardship. The examples showed how extensive classifications could be conducted for all activities across construction and post-construction phases of infrastructure projects to associate them with different combinations of protection measures.

The examples also demonstrated how it is possible to create a set of tools (predictive scientific assessments, decision trees, etc.) and bring these elements together to strike a balance of complexity and usability. However, to strike a parsimonious balance, simplifications were necessary. Post-construction stressors for the ongoing case study were reduced to focus on toxicity via stormwater runoff, but there are other important stressors such as hydromodification and erosion that can occur during this phase (Walsh et al. 2005, Wemple et al. 2018, Wheeler et al. 2005). The key stressor of the construction phase was determined to be from bedded sediments, but suspended sediments can also have adverse effects on aquatic biota such as fish. A risk currency and accounting system described in the general framework may also be difficult to navigate with stakeholders to achieve their goals and objectives since calibration of the final scoring is ultimately a policy decision. Despite these caveats, the framework is a step forward towards improved protection and practical, long-term regulatory efficiency. It does not represent a final product, but instead should continue to be refined and updated with the best available science, measures, models, and expert judgement.

The general framework should serve as a foundation for further development and a beginning of balancing simplicity and complexity in regulatory processes. The focus of future research and further refinement could be on more applications, additional scientific analyses, a broader range of benefits and values, and other types of performance metrics. Going forward, there need to be more applications and case studies to gather additional results and outcomes that will help provide feedback for improvement, refinement, and better understanding of the framework. For example, by following a “piggyback” strategy, where improved solutions are offered during expansions, retrofits, and maintenance, the framework be applied with the opportunity for additional refinement from multiple organizations in different sectors (e.g., conservation groups and infrastructure agencies) (Neeson et al. 2018). Ongoing refinement of the predictive scientific assessments, such as with a Bayesian approach, will require different types of analyses to be used within the general framework. Pahl-Wostl (2007) supports the use of other types of analyses such as economic assessments during decision-making processes. Implementing uncertainty analyses would reinforce framework decisions and help project-proponents understand the risk of protection measure combinations especially when projects and management actions have the potential to have adverse consequences if employed incorrectly (NRC 2001). Sensitivity analyses may also be useful by pointing out the most critical processes and variables to guide data collection. Predictive scientific assessment tools can also be improved by identifying additional stressors during each phase of land development and infrastructure projects, including better statistical and mechanistic models, and distinguishing different responses of biota and waterbodies to potential stressors (e.g., bedded vs. suspended sediment).

Sustainable management of an aquatic system should sit upon three key pillars: economic efficiency, environmental sustainability, and social equity (Dyson et al. 2003). Our framework is based upon a technical approach to address ecological functions and cost effectiveness, but lacks a social aspect, which is equally important to consider. Considering a broader range of social, economic, and environmental benefits and values could serve to bolster the general framework and allow project-proponents and stakeholders to have even more flexibility. For example, protective measures could be used to also improve flood protection for at-risk communities, increase recreation opportunities, and benefit fisheries (Bridges et al. 2015). As discussed in the general framework, there is a need for a so-called ‘risk currency’ or metric that allows assessments within the framework to be compared across phases of development, different waterbodies, etc. Further research needs to be done on more metrics that can be integrated into the framework to broaden its scope for several different types of management actions and infrastructure development. For example, if the USACE was hoping to implement the framework within their Natural Infrastructure Opportunities Tool (Altman n.d.) when trying to reduce the risk of nature-based solutions disrupting coastal sediment regimes, metrics associated with sediment accretions or deficits would be needed.

Our novel framework has begun to lay the foundation for a new way to approach protection measure planning and management. It shifts management away from unnecessary fragmentation and separation of regulations and policies as well as the paradigm of being oversimplified or extremely complex. The framework was designed with the intent of being transferable and relevant to other types of land development and infrastructure projects where it can continue to be adapted and refined. It argues that the initial work and predictive scientific assessments required will streamline processes and efforts, leading to a more effective, tailored protection measures that ensures the ecological functions of aquatic systems are increased by every project.

Chapter 3 References

Ackerman, D. and Stein, E.D. (2008) Evaluating the Effectiveness of Best Management Practices Using Dynamic Modeling. Journal of Environmental Engineering 134(8), 628-639.

Altman, S. (n.d.) Using the Natural Infrastructure Opportunities Tool (NIOT) User's Guide.

Angermeier, P.L., Wheeler, A.P. and Rosenberger, A.E. (2004) A Conceptual Framework for Assessing Impacts of Roads on Aquatic Biota. Fisheries 29(12), 19-29.

ASCE (2017) Infrastructure Report Card: A Comprehensive Assessment of America's Infrastructure, p. 110, American Society of Civil Engineers.

Beck, M.W., Mazor, R.D., Johnson, S., Wisenbaker, K., Westfall, J., Ode, P.R., Hill, R., Loflen, C., Sutula, M. and Stein, E.D. (2019) Prioritizing Management Goals for Stream Biological Integrity within the Developed Landscape Context. Freshwater Science 38(4), 883-898.

Bestgen, K.R., Poff, N.L., Baker, D.W., Bledsoe, B.P., Merritt, D.M., Lorie, M., Auble, G.T., Sanderson, J.S. and Kondratieff, B.C. (2020) Designing Flows to Enhance Ecosystem Functioning in Heavily Altered Rivers. Ecological Applications 30(1), e02005.

Bledsoe, B. (2007) Framework for Risk-Based Assessment of Stream Response to Urbanization. Cities of the Future: Towards Integrated Sustainable Water and Landscape Management, 141-156.

Bledsoe, B.P., Brown, M.C. and Raff, D.A. (2007) GeoTools: A Toolkit for Fluvial System Analysis. Journal of the American Water Resources Association 43(3), 757-772.

Bledsoe, B.P., Stein, E.D., Hawley, R.J. and Booth, D. (2012) Framework and Tool for Rapid Assessment of Stream Susceptibility to Hydromodification. Journal of the American Water Resources Association 48(4), 788-808.

Booth, D.B. and Bledsoe, B.P. (2009) Streams and Urbanization. The Water Environment of Cities, pp. 93-123, Springer, Boston, MA.

Bridges, T.S., Wagner, P.W., Burks-Copes, K.A., Bates, M.E., Collier, Z.A., Fischenich, J.C., Gailani, J.Z., Leuck, L.D., Piercy, C.D., Rosati, J.D., Russo, E.J., Shafer, D.J., Suedel, B.C., Vuxton, E.A., and Wamsley, T.V. (2015) Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience, U.S. Army Corps of Engineers Research and Development Center, Environmental Laboratory.

Clary, J., Jones, J., Leisenring, M., Hobson, P. and Strecker, E. (2017) International Stormwater Best Management Practices (BMP) Database Summary Statistics. Wright Water Engineers and Geosyntec Consultants for Water Environment & Reuse Foundation with Support from the Urban Drainage and Flood Control District and the City and County of Denver.

Cocchiglia, L., Purcell, P.J. and Kelly-Quinn, M. (2012) A Critical Review of the Effects of Motorway River-Crossing Construction on the Aquatic Environment. Freshwater Reviews 5(2), 141-168.

Coles, J.F., McMahon, G., Bell, A.H., Brown, L.R., Fitzpatrick, F.A., Scudder Eikenberry, B.C., Woodside, M.D., Cuffney, T.F., Bryant, W.L., Cappiella, K., Fraley-McNeal, L. and Stack, W.P. (2012) Effects of Urban Development on Stream Ecosystems in Nine

Metropolitan Study Areas Across the United States. U.S. Geological Survey Circular (1373), 138 p.

Dyson, M., Bergkamp, G. and Scanlon, J. (2003) Flow - The Essentials of Environmental Flows, 2nd Edition. IUCN, Gland, Switzerland.

EPA (2017) National Water Quality Inventory: Report to Congress, Environmental Protection Agency.

Esty, D.C. (1999) Toward Optimal Environmental Governance. NYUL Rev. 74, 1495.

Feldman, D.L., Sengupta, A., Stuvick, L., Stein, E., Pettigrove, V. and Arora, M. (2015) Governance Issues in Developing and Implementing Offsets for Water Management Cenefits: Can Preliminary Evaluation Guide Implementation Effectiveness? Wiley Interdisciplinary Reviews: Water 2(2), 121-130.

Freeman, J. and Farber, D.A. (2004) Thirty-Fourth Annual Administrative Law Issue-Modular Environmental Regulation. Duke LJ 54, 795.

GAO (2012) Nonpoint Source Water Pollution: Greater Oversight and Additional Data Needed for Key EPA Water Program. U.S. Government Accountability Office.

Jacobson, R., Femmer, S.R. and McKenney, R.A. (2001) Land-Use Changes and the Physical Habitat of Streams - A Review with Emphasis on Studies Within the U.S. Geological Survey Federal - State Cooperative Program. Circular 1175, 131-152.

Karkkainen, B.C. (2002) Adaptive Ecosystem Management and Regulatory Penalty Defaults: Toward a Bounded Pragmatism. Minn. L. Rev. 87, 943.

Kwak, T.J. and Freeman, M.C. (2010) Assessment and Management of Ecological Integrity: Chapter 12, 353-394. American Fisheries Society, Bethesda, MD.

Logan, D.T. (2007) Perspective on Ecotoxicology of PAHs to Fish. Human and Ecological Risk Assessment 13(2), 302-316.

Mas, D.M. (2003) A Comparison of Three Key Elements of National and Select State Environmental Policy Acts. Environmental Practice 5(4), 349-362.

Montgomery, D.R. and MacDonald, L.H. (2002) Diagnostic Approach to Stream Channel Assessment and Monitoring. Journal of the American Water Resources Association 38(1), 1-16.

Murphy, B. (2020) Urban Stream Assessment Procedure: A Framework for Assessing Stream Health in the Urban Environment. Watershed Management Conference 2020: A Clear Vision of Watershed Management, pp. 99-108, American Society of Civil Engineers, Reston, VA.

Nelson, J.M., Stephens, T.A., Bringolf, R.B., Calabria, J., Freeman, B.J., Hill, K.S., Mattison, W.H., Melchionni, B.P., Skaggs, J.W., Vick, A., Bledsoe, B.P., and Wenger, S.J. (2021) Review of Special Provisions and Other Conditions Placed on GDOT Projects For Imperiled Aquatic Species Protection, Volumes I-III.

NRC (2001) Assessing the TMDL Approach to Water Quality Management, National Academies Press.

Pahl-Wostl, C. (2007) Transitions Towards Adaptive Management of Water Facing Climate and Global Change. Water Resources Management 21(1), 49-62.

Palmer, M.A., Hondula, K.L. and Koch, B.J. (2014) Ecological restoration of streams and rivers: shifting strategies and shifting goals. Annual Review of Ecology, Evolution, and Systematics 45, 247-269.

Poff, N.L. and Allan, J.D. (1995) Functional Organization of Stream Fish Assemblages in Relation to Hydrological Variability. Ecology 76(2), 606-627.

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G, Merritt, D.M., O'Keeffe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., and Warner, A. (2010) The Ecological Limits of Hydrologic Alteration (ELOHA): A New Framework for Developing Regional Environmental Flow Standards. Freshwater Biology 55(1), 147-170.

Rankin, E.T. (1995) Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. pp. 181-208, Lewis Publishers.

Reckhow, K.H. (1999) Lessons From Risk Assessment. Human and Ecological Risk Assessment: An International Journal 5(2), 245-253.

United Nations (2019) World Urbanization Prospects: The 2018 Revision, United Nations, New York.

Vietz, G.J., Rutherfurd, I.D., Fletcher, T.D. and Walsh, C.J. (2016) Thinking Outside the Channel: Challenges and Opportunities for Protection and Restoration of Stream Morphology in Urbanizing Catchments. Landscape and Urban Planning 145, 34-44.

Wachal, D.J., Banks, K.E., Hudak, P.F. and Harmel, R.D. (2009) Modeling Erosion and Sediment Control Practices with RUSLE 2.0: A Management Approach for Natural Gas Well Sites in Denton County, TX, USA. Environmental Geology 56(8), 1615-1627.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M. and Morgan, R.P. (2005) The Urban Stream Syndrome: Current Knowledge and the Search for a Cure. Journal of the North American Benthological Society 24(3), 706-723.

Waters, T.F. (1995) Sediment in Streams: Sources, Biological Effects, and Control, American Fisheries Society, Bethesda, Maryland.

Wemple, B.C., Browning, T., Ziegler, A.D., Celi, J., Chun, K.P.S., Jaramillo, F., Leite, N.K., Ramchunder, S.J., Negishi, J.N., Palomeque, X. and Sawyer, D. (2018) Ecohydrological Disturbances Associated with Roads: Current Knowledge, Research Needs, and Management Concerns with Reference to the Tropics. Ecohydrology 11(3), e1881.

Wenger, S.J., Roy, A.H., Jackson, C.R., Bernhardt, E.S., Carter, T.L., Filoso, S., Gibson, C.A., Hession, W.C., Kaushal, S.S., Martí, E., Meyer, J.L., Palmer, M.A., Paul, M.J., Purcell, A.H., Ramírez, A., Rosemond, A.D., Schofield, K.A., Sudduth, E.B. and Walsh, C.J. (2009) Twenty-Six Key Research Questions in Urban Stream Ecology: An Assessment of the State of the Science. Journal of the North American Benthological Society 28(4), 1080-1098.

Wheeler, A.P., Angermeier, P.L. and Rosenberger, A.E. (2005) Impacts of New Highways and Subsequent Landscape Urbanization on Stream Habitat and Biota. Reviews in Fisheries Science 13(3), 141-164.

CHAPTER 4

CONCLUSIONS

Population growth and land development coupled with other exacerbating factors such as climate change will continue to increase pressures on aquatic ecosystems (Jacobson et al. 2001, United Nations 2019, Walsh et al. 2005, Wenger et al. 2009). This study represents an effort to transcend one-size-fits-all management practices and dispersed regulatory programs with limited ability to effectively and holistically address these mounting stressors (Freeman and Farber 2004, Nelson et al. 2021).

To provide a foundation for the new management framework developed in this study, a summary literature review (Chapter 2) of stressors and protection measures, associated with a wide range of construction activities summarized, synthesized current information and highlighted a number of substantial gaps in current understanding, especially with respect to non-sediment related protection measures and evidence of performance in realistic field settings. Nevertheless, there appears to be sufficient knowledge about a wide range of measures to provide a basis for the framework and improve the range and flexibility of measures employed in land development and infrastructure projects. The review also revealed opportunities for recommending forty-eight protection measures with demonstrated efficacy that lacked consistent application across local, state, and federal jurisdictions and management plans. Studies on protection measure efficacies need to be broadened to include more types of measures and simulate field settings for accurate performances. Continuing to obtain additional knowledge and data on protection measures (e.g., effectiveness, operation and maintenance, etc.) to build an evidence base for performance will help fill the gaps and benefit future research and applications.

The extensive inventory of protection measures (Appendix) from local, state, and federal agencies from around the U.S. indicates that all agencies and programs have room for improvement and can benefit from exchanging knowledge and best available measures. Pairing these types of inventories with periodic literature reviews will help increase empirical knowledge of measures and facilitate selections of combinations of protection measures that effectively protect waterbodies and biota from stressors to which they are most vulnerable.

The general framework provides the opportunity for stakeholders to thoroughly evaluate and optimize management strategies using alternative combinations of protection measures across construction and post-construction phases to achieve improved ecological outcomes. Investment of time and effort up front (e.g., the literature review in Chapter 2 and inventory, organization, classification, screening, and recommendation of protection measures in Appendix) to build an empirical basis, inventory best available measures and construction and post-construction-related activities, classify measures and activities by potential stressors, and construct predictive models (e.g., scientific assessments) that link susceptibilities of biota and waterbodies to protective measures that best reduce potential stressors yields regulatory efficiencies and more effective protection from key stressors. This novel approach streamlines regulatory processes, enables improved stewardship of natural resources, and increases cost-effectiveness. However, the framework still needs additional testing and future refinement to strike a balance of simplicity and complexity, improve usability and clarity, increase scientific bases, and provide guidance on implementation. It requires knowledge updating to include the best available protection measures and science. Maintaining flexibility, adaptability, and transparency will ensure the framework can be applied to diverse types of land development and infrastructure projects in the future to protect aquatic ecosystems.

References

Ackerman, D. and Stein, E.D. (2008) Evaluating the Effectiveness of Best Management Practices Using Dynamic Modeling. Journal of Environmental Engineering 134(8), 628-639.

ADOT (2015) Arizona Department of Transportation Herbicide Treatment Program on Bureau of Land Management Lands in Arizona.

Altman, S. (n.d.) Using the Natural Infrastructure Opportunities Tool (NIOT) User's Guide.

Álvarez-Mozos, J., Abad, E., Giménez, R., Campo, M.A., Goñi, M., Arive, M., Casalí, J., Díez, J. and Diego, I. (2014) Evaluation of Erosion Control Geotextiles on Steep Slopes. Part 1: Effects on Runoff and Soil Loss. Catena 118, 168-178.

Andersson, Å.C. and Strömvall, A.-M. (2001) Leaching of Concrete Admixtures Containing Thiocyanate and Resin Acids. Environmental Science & Technology 35(4), 788-793.

Angermeier, P.L., Wheeler, A.P. and Rosenberger, A.E. (2004) A Conceptual Framework for Assessing Impacts of Roads on Aquatic Biota. Fisheries 29(12), 19-29.

ASCE (2001) Environmental Technology Verification Report for Installation of Silt Fence Using the Tommy Static Slicing Method. American Society of Civil Engineers.

ASCE (2017) Infrastructure Report Card: A Comprehensive Assessment of America's Infrastructure, p. 110. American Society of Civil Engineers.

Bakr, N., Weindorf, D.C., Zhu, Y., Arceneaux, A.E. and Selim, H. (2012) Evaluation of Compost/Mulch as Highway Embankment Erosion Control in Louisiana at the Plot-Scale. Journal of Hydrology 468, 257-267.

Barrett, M.E., Kearney, J.E., McCoy, T.G. and Malina Jr, J.F. (1995) An Evaluation of the Use and Effectiveness of Temporary Sediment Controls. Center for Research in Water Sciences, Bureau of Engineering Research, The University of Texas at Austin, CRWR Online Report 95-6.

Barrett, M.E., Malina Jr, J.F. and Charbeneau, R.J. (1998) An Evaluation of Geotextiles for Temporary Sediment Control. Water Environment Research 70(3), 283-290.

Beck, M.W., Mazor, R.D., Johnson, S., Wisenbaker, K., Westfall, J., Ode, P.R., Hill, R., Loflen, C., Sutula, M. and Stein, E.D. (2019) Prioritizing Management Goals for Stream Biological Integrity within the Developed Landscape Context. Freshwater Science 38(4), 883-898.

Beighley, R.E., Scholl, B., Faucette, L.B. and Governo, J. (2010) Runoff Characteristics for Construction Site Erosion Control Practices. Journal of Irrigation and Drainage Engineering 136(6), 405-413.

Benik, S., Wilson, B., Biesboer, D., Hansen, B. and Stenlund, D. (2003) Performance of Erosion Control Products on a Highway Embankment. Transactions of the ASABE 46(4), 1113.

Bernhardt, E.S. and Palmer, M.A. (2007) Restoring Streams in an Urbanizing World. Freshwater Biology 52(4), 738-751.

Bestgen, K.R., Poff, N.L., Baker, D.W., Bledsoe, B.P., Merritt, D.M., Lorie, M., Auble, G.T., Sanderson, J.S. and Kondratieff, B.C. (2020) Designing Flows to Enhance Ecosystem Functioning in Heavily Altered Rivers. Ecological Applications 30(1), e02005.

Birt, L., Persyn, R. and Smith, P. (2007) Evaluation of Texas Compost Specifications for Stormwater Erosion Control. Transactions of the ASABE 50(3), 955-960.

Bledsoe, B. (2007) Framework for Risk-Based Assessment of Stream Response to Urbanization. Cities of the Future: Towards Integrated Sustainable Water and Landscape Management, 141-156.

Bledsoe, B.P., Brown, M.C. and Raff, D.A. (2007) GeoTools: A Toolkit for Fluvial System Analysis. Journal of the American Water Resources Association 43(3), 757-772.

Bledsoe, B.P., Stein, E.D., Hawley, R.J. and Booth, D. (2012) Framework and Tool for Rapid Assessment of Stream Susceptibility to Hydromodification. Journal of the American Water Resources Association 48(4), 788-808.

Booth, D.B. and Bledsoe, B.P. (2009) Streams and Urbanization. The Water Environment of Cities, pp. 93-123, Springer, Boston, MA.

Booth, D.B. and Jackson, C.R. (1997) Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection, and the Limits of Mitigation. Journal of the American Water Resources Association 33(5), 1077-1090.

BPA (2016) HIP III Handbook: Unabbreviated Guidance of Biological Opinion Requirements and RRT Process.

Bridges, T.S., Wagner, P.W., Burks-Copes, K.A., Bates, M.E., Collier, Z.A., Fischenich, J.C., Gailani, J.Z., Leuck, L.D., Piercy, C.D., Rosati, J.D., Russo, E.J., Shafer, D.J., Suedel, B.C., Vuxton, E.A., and Wamsley, T.V. (2015) Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience, U.S. Army Corps of Engineers Research and Development Center, Environmental Laboratory.

Bugg, R.A., Donald, W., Zech, W. and Perez, M. (2017) Performance Evaluations of Three Silt Fence Practices Using a Full Scale Testing Apparatus. Water 9(7).

Burns, S.E. and Troxel, C.F. (2015) Life Cycle Cost Assessment and Performance Evaluation of Sediment Control Technologies, Georgia. Department of Transportation. Office of Research.

CDOT (2002) Erosion Control and Stormwater Quality Guide. Colorado Department of Transportation.

Chapman, J.M., Proulx, C.L., Veilleux, M.A., Levert, C., Bliss, S., Andre, M.-E., Lapointe, N.W. and Cooke, S.J. (2014) Clear as Mud: A Meta-Analysis on the Effects of Sedimentation on Freshwater Fish and the Effectiveness of Sediment-Control Measures. Water Research 56, 190-202.

Clary, J., Jones, J., Leisenring, M., Hobson, P. and Strecker, E. (2017) International Stormwater Best Management Practices (BMP) Database Summary Statistics. Wright Water Engineers and Geosyntec Consultants for Water Environment & Reuse Foundation with Support from the Urban Drainage and Flood Control District and the City and County of Denver.

Cocchiglia, L., Purcell, P.J. and Kelly-Quinn, M. (2012) A Critical Review of the Effects of Motorway River-Crossing Construction on the Aquatic Environment. Freshwater Reviews 5(2), 141-168.

Coles, J.F., McMahon, G., Bell, A.H., Brown, L.R., Fitzpatrick, F.A., Scudder Eikenberry, B.C., Woodside, M.D., Cuffney, T.F., Bryant, W.L., Cappiella, K., Fraley-McNeal, L. and Stack, W.P. (2012) Effects of Urban Development on Stream Ecosystems in Nine

Metropolitan Study Areas Across the United States. U.S. Geological Survey Circular (1373), 138 p.

Cooke, S., Chapman, J. and Vermaire, J. (2015) On the Apparent Failure of Silt Fences to Protect Freshwater Ecosystems from Sedimentation: A Call for Improvements in Science, Technology, Training and Compliance monitoring. Journal of Environmental Management 164, 67-73.

Dahl, P.H., de Jong, C.A. and Popper, A.N. (2015) The Underwater Sound Field From Impact Pile Driving and its Potential Effects on Marine Life. Acoustics Today 11(2), 18-25.

Demars, K.R., Long, R.P. and Ives, J.R. (2000) Use of Wood Waste Materials for Erosion Control, Citeseer.

Deng, Q., Jiang, W. and Zhang, W. (2016) Theoretical Investigation of the Effects of the Cushion on Reducing Underwater Noise from Offshore Pile Driving. The Journal of the Acoustical Society of America 140(4), 2780-2793.

Dyson, M., Bergkamp, G. and Scanlon, J. (2003) Flow - The Essentials of Environmental Flows, 2nd Edition. IUCN, Gland, Switzerland.

EPA (1993) Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. Environmental Protection Agency, Washington, DC.

EPA (2005) National Management Measures to Control Nonpoint Source Pollution From Urban Areas. Environmental Protection Agency, Cincinnati, OH (Management Measure 8: Construction Site Erosion, Sediment, and Chemical Control).

EPA (2017) National Water Quality Inventory: Report to Congress, Environmental Protection Agency.

Esty, D.C. (1999) Toward Optimal Environmental Governance. NYUL Rev. 74, 1495.

Faucette, L., Governo, J., Tyler, R., Gigley, G., Jordan, C. and Lockaby, B. (2009a) Performance of Compost Filter Socks and Conventional Sediment Control Barriers Used for Perimeter Control on Construction Sites. Journal of Soil and Water Conservation 64(1), 81-88.

Faucette, L., Jordan, C., Risse, L., Cabrera, M., Coleman, D. and West, L. (2005) Evaluation of Stormwater From Compost and Conventional Erosion Control Practices in Construction Activities. Journal of Soil and Water Conservation 60(6), 288-297.

Faucette, L., Scholl, B., Beighley, R. and Governo, J. (2009b) Large□Scale Performance and Design for Construction Activity Erosion Control Best Management Practices. Journal of Environmental Quality 38(3), 1248-1254.

Faucette, L.B., Risse, L.M., Jordan, C.F., Cabrera, M.L., Coleman, D.C. and West, L.T. (2006) Vegetation and Soil Quality Effects From Hydroseed and Compost Blankets Used for Erosion Control in Construction Activities. Journal of Soil and Water Conservation 61(6), 355-362.

Feldman, D.L., Sengupta, A., Stuvick, L., Stein, E., Pettigrove, V. and Arora, M. (2015) Governance Issues in Developing and Implementing Offsets for Water Management Cenefits: Can Preliminary Evaluation Guide Implementation Effectiveness? Wiley Interdisciplinary Reviews: Water 2(2), 121-130.

Fisher, L.S. and Jarrett, A. (1984) Sediment Retention Efficiency of Synthetic Filter Fabrics. Transactions of the ASABE 27(2), 429-0436.

Freeman, J. and Farber, D.A. (2004) Thirty-Fourth Annual Administrative Law Issue-Modular Environmental Regulation. Duke LJ 54, 795.

FWS (2006) Guidelines for the Protection of Marine Animals During the Use of Explosives In the Waters of the State of Florida. U.S. Fish and Wildlife Services.

GAO (2012) Nonpoint Source Water Pollution: Greater Oversight and Additional Data Needed for Key EPA Water Program. U.S. Government Accountability Office.

GSWCC (2016) Manual For Erosion and Sediment Control in Georgia. Georgia Soil and Water Conservation Commission, Athens, GA.

Guerin, T. (2014) Root Causes of Fluid Spills From Earthmoving Plant and Equipment: Implications for Reducing Environmental and Safety Impacts. Engineering Failure Analysis 45, 128-141.

Harbor, J. (1999) Engineering Geomorphology at the Cutting Edge of Land Disturbance: Erosion and Sediment Control on Construction Sites. Geomorphology 31(1-4), 247-263.

Jacobson, R., Femmer, S.R. and McKenney, R.A. (2001) Land-Use Changes and the Physical Habitat of Streams - A Review with Emphasis on Studies Within the U.S. Geological Survey Federal - State Cooperative Program. Circular 1175, 131-152.

Karkkainen, B.C. (2002) Adaptive Ecosystem Management and Regulatory Penalty Defaults: Toward a Bounded Pragmatism. Minn. L. Rev. 87, 943.

Kaufman, M.M. (2000) Erosion Control at Construction Sites: The Science–Policy Gap.

Keevin, T.M. (1998) A Review of Natural Resource Agency Recommendations for Mitigating the Impacts of Underwater Blasting. Reviews in Fisheries Science 6(4), 281-313.

Keevin, T.M. and Hempen, G.L. (1997) The Environmental Effects of Underwater Explosions With Methods to Mitigate Impacts, U.S. Army Corps of Engineers, St. Louis District.

Kurda, R., Silvestre, J.D. and de Brito, J. (2018) Toxicity and Environmental and Economic Performance of Fly Ash and Recycled Concrete Aggregates Use in Concrete: A Review. Heliyon 4(4), e00611.

Kwak, T.J. and Freeman, M.C. (2010) Assessment and Management of Ecological Integrity: Chapter 12, 353-394. American Fisheries Society, Bethesda, MD.

Landis, T.D., Wilkinson, K.M., Steinfeld, D.E., Riley, S.A. and Fekaris, G.N. (2005) Roadside Revegetation of Forest Highways: New Applications for Native Plants. Native Plants Journal 6(3), 297-305.

Lebow, S.T., Cooper, P. and Lebow, P.K. (2004) Variability in Evaluating Environmental Impacts of Treated Wood. Department of Agriculture, Forest Service, Forest Products Laboratory, FPL-RP-620, 1-10.

Lebow, S.T. and Tippie, M. (2001) Guide for Minimizing the Effect of Preservative-Treated Wood on Sensitive Environments. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, FLP-GTR-122, 18 p.

Lee, G., McLaughlin, R., Whitely, K. and Brown, V. (2018) Evaluation of Seven Mulch Treatments for Erosion Control and Vegetation Establishment on Steep Slopes. Journal of Soil and Water Conservation 73(4), 434-442.

Line, D. and White, N. (2001) Efficiencies of Temporary Sediment Traps on Two North Carolina Construction Sites. Transactions of the ASABE 44(5), 1207.

Logan, D.T. (2007) Perspective on Ecotoxicology of PAHs to Fish. Human and Ecological Risk Assessment 13(2), 302-316.

Mas, D.M. (2003) A Comparison of Three Key Elements of National and Select State Environmental Policy Acts. Environmental Practice 5(4), 349-362.

McLaughlin, R.A. (2002) Measures to Reduce Erosion and Rurbidity in Construction Site Runoff, North Carolina State University.

Meyer, L., Wischmeier, W. and Foster, G. (1970) Mulch Rates Required for Erosion Control on Steep Slopes. Soil Science Society of America Journal 34(6), 928-931.

Mocová, K., Sackey, L. and Renkerová, P. (2019) Environmental Impact of Concrete and Concrete-Based Construction Waste Leachates. IOP Conference Series: Earth and Environmental Science 290 (1), 012023.

Montgomery, D.R. and MacDonald, L.H. (2002) Diagnostic Approach to Stream Channel Assessment and Monitoring. Journal of the American Water Resources Association 38(1), 1-16.

Morledge, R. and Jackson, F. (2001) Reducing Environmental Pollution Caused by Construction Plant. Environmental Management and Health 12(2), 191-206.

Morrow, S., Smolen, M., Stiegler, J., Cole, J. and Protection, T. (2003) Using Vegetation for Erosion Control on Construction Sites. Oklahoma Cooperative Extension Service BAE-1514. Available online: http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2264/BAE-1514web.pdf.

Murphy, B. (2020) Urban Stream Assessment Procedure: A Framework for Assessing Stream Health in the Urban Environment. Watershed Management Conference 2020: A Clear Vision of Watershed Management, pp. 99-108, American Society of Civil Engineers, Reston, VA.

Nearing, M., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., Le Bissonnais, Y., Nichols, M., Nunes, J., Renschler, C., Souchere, V., and van Oost, K. (2005) Modeling Response of Soil Erosion and Runoff to Changes in Precipitation and Cover. Catena 61(2-3), 131-154.

Nelson, J.M., Stephens, T.A., Bringolf, R.B., Calabria, J., Freeman, B.J., Hill, K.S., Mattison, W.H., Melchionni, B.P., Skaggs, J.W., Vick, A., Bledsoe, B.P., and Wenger, S.J. (2021) Review of Special Provisions and Other Conditions Placed on GDOT Projects For Imperiled Aquatic Species Protection, Volumes I-III.

NOAA (2003) Non-Fishing Impacts to Essential Fish Habitat and Recommended Conservation Measures. National Oceanic and Atmospheric Administration.

NOAA (2017) Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion City and Borough of Sitka Gary Paxton Industrial Park Multipurpose Dock Project Sawmill Cove. National Oceanic and Atmospheric Administration, Sitka, Alaska.

NRC (2001) Assessing the TMDL Approach to Water Quality Management, National Academies Press.

NRCS (2000) Erosion and Sedimentation on Construction Sites. U.S. Department of Agriculture, Auburn, AL.

NRCS (2008) Urban Soil Erosion and Sediment Control. U.S. Department of Agriculture, Association of Illinois Soil and Water Conservation Districts.

Ormerod, S.J., Dobson, M., Hildrew, A.G. and Townsend, C. (2010) Multiple stressors in freshwater ecosystems, Wiley Online Library.

Pahl-Wostl, C. (2007) Transitions Towards Adaptive Management of Water Facing Climate and Global Change. Water Resources Management 21(1), 49-62.

Palmer, M.A., Hondula, K.L. and Koch, B.J. (2014) Ecological Restoration of Streams and Rivers: Shifting Strategies and Shifting Goals. Annual Review of Ecology, Evolution, and Systematics 45, 247-269.

Poff, N.L. and Allan, J.D. (1995) Functional Organization of Stream Fish Assemblages in Relation to Hydrological Variability. Ecology 76(2), 606-627.

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G, Merritt, D.M., O'Keeffe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., and Warner, A. (2010) The Ecological Limits of Hydrologic Alteration (ELOHA): A New Framework for Developing Regional Environmental Flow Standards. Freshwater Biology 55(1), 147-170..

Popper, A.N. and Hastings, M.C. (2009) The Effects of Anthropogenic Sources of Sound on Fishes. Journal of Fish Biology 75(3), 455-489.

Prosdocimi, M., Tarolli, P. and Cerdà, A. (2016) Mulching Practices for Reducing Soil Water Erosion: A Review. Earth-Science Reviews 161, 191-203.

Pudasaini, M., Shrestha, S. and Riley, S. (2004) Soil Erosion Control From Construction Sites: An Important Aspect of Watershed Conservation. In Self Sustaining Solutions for Streams, Wetlands, and Watersheds, p. 24, American Society of Agricultural and Biological Engineers.

Rankin, E.T. (1995) Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. pp. 181-208, Lewis Publishers.

Reckhow, K.H. (1999) Lessons from risk assessment. Human and Ecological Risk Assessment: An International Journal 5(2), 245-253.

Reichenberger, S., Bach, M., Skitschak, A. and Frede, H.-G. (2007) Mitigation Strategies to Reduce Pesticide Inputs Into Ground-and Surface Water and Their Effectiveness; A Review. Science of the Total Environment 384(1-3), 1-35.

Reid, D. and Church, M. (2015) Geomorphic and Ecological Consequences of Riprap Placement in River Systems. Journal of the American Water Resources Association 51(4), 1043-1059.

Rickson, R. (2006) Controlling Sediment at Source: An Evaluation of Erosion Control Geotextiles. Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group 31(5), 550-560.

Risse, L., Thompson, S., Governo, J. and Harris, K. (2008) Testing of New Silt Fence Materials: A Case Study of a Belted Strand Retention Fence. Journal of Soil and Water Conservation 63(5), 265-273.

Risse, L.M., Faucette, L.B., Gaskin, J.W., Jordan, C.F., Cabrera, M.L. and West, L.T. (2005) Field Evaluation of Compost and Mulches for Erosion Control, Georgia Institute of Technology.

Sadeghi, A., Faucette, B., and Sefton, K. (2006) Sediment and Nutrient Removal From Storm Runoff with Compost Filter Socks and Silt Fence. In 2006 American Society of Agriculture and Biological Engineers Annual International Conference, Portland, OR.

Schwartz, J.S. and Hathaway, J.M. (2018) In-Service Performance Evaluation of Erosion Prevention and Sediment Control (EPSC) Devices, Tennessee Department of Transportation.

Segner, H., Schmitt-Jansen, M. and Sabater, S. (2014) Assessing the Impact of Multiple Stressors on Aquatic Biota: The Receptor's Side Matters. Environmental Science & Technology 48, 7690-7696.

Sidhu, R. (2015) Effectiveness of Selected Erosion Control Covers During Vegetation Establishment Under Simulated Rainfall.

Smets, T., Poesen, J. and Knapen, A. (2008) Spatial Scale Effects on the Effectiveness of Organic Mulches in Reducing Soil Erosion by Water. Earth-Science Reviews 89(1-2), 1-12.

Soupir, M.L., Mostaghimi, S., Masters, A., Flahive, K.A., Vaughan, D.H., Mendez, A. and McClellan, P.W. (2004) Effectiveness of Polyacrylamide (PAM) in Improving Runoff Water Quality from Construction Sites. Journal of the American Water Resources Association 40(1), 53-66.

Stein, E.D., Cover, M.R., Elizabeth Fetscher, A., O'Reilly, C., Guardado, R. and Solek, C.W. (2013) Reach□Scale Geomorphic and Biological Effects of Localized Streambank Armoring. Journal of the American Water Resources Association 49(4), 780-792.

Sutherland, R.A. and Ziegler, A.D. (2007) Effectiveness of Coir-Based Rolled Erosion Control Systems in Reducing Sediment Transport From Hillslopes. Applied Geography 27(3-4), 150-164.

Syverson, N. and Bechmann, M. (2004) Vegetative Buffer Zones as Pesticide Filters for Simulated Surface Runoff. Ecological Engineering 22(3), 175-184.

Tyner, J., Yoder, D., Chomicki, B. and Tyagi, A. (2011) A Review of Construction Site Best Management Practices for Erosion Control. Transactions of the ASABE 54(2), 441-450.

United Nations (2019) World Urbanization Prospects: The 2018 Revision, United Nations, New York.

USDOT (2020) Transportation Statistics Annual Report 2020, U.S. Department of Transportation.

Vietz, G.J., Rutherfurd, I.D., Fletcher, T.D. and Walsh, C.J. (2016) Thinking Outside the Channel: Challenges and Opportunities for Protection and Restoration of Stream Morphology in Urbanizing Catchments. Landscape and Urban Planning 145, 34-44.

Wachal, D.J., Banks, K.E., Hudak, P.F. and Harmel, R.D. (2009) Modeling Erosion and Sediment Control Practices with RUSLE 2.0: A Management Approach for Natural Gas Well Sites in Denton County, TX, USA. Environmental Geology 56(8), 1615-1627.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M. and Morgan, R.P. (2005) The Urban Stream Syndrome: Current Knowledge and the Search for a Cure. Journal of the North American Benthological Society 24(3), 706-723.

Waters, T.F. (1995) Sediment in Streams: Sources, Biological Effects, and Control, American Fisheries Society, Bethesda, MD.

Wemple, B.C., Browning, T., Ziegler, A.D., Celi, J., Chun, K.P.S., Jaramillo, F., Leite, N.K., Ramchunder, S.J., Negishi, J.N., Palomeque, X. and Sawyer, D. (2018) Ecohydrological Disturbances Associated with Roads: Current Knowledge, Research Needs, and Management Concerns with Reference to the Tropics. Ecohydrology 11(3), e1881.

Wenger, S.J., Roy, A.H., Jackson, C.R., Bernhardt, E.S., Carter, T.L., Filoso, S., Gibson, C.A., Hession, W.C., Kaushal, S.S., Martí, E., Meyer, J.L., Palmer, M.A., Paul, M.J., Purcell, A.H., Ramírez, A., Rosemond, A.D., Schofield, K.A., Sudduth, E.B. and Walsh, C.J. (2009) Twenty-Six Key Research Questions in Urban Stream Ecology: An Assessment of the State of the Science. Journal of the North American Benthological Society 28(4), 1080-1098.

Weston, D.P., Lentz, R.D., Cahn, M.D., Ogle, R.S., Rothert, A.K. and Lydy, M.J. (2009) Toxicity of Various Anionic Polyacrylamide Formulations When Used as Erosion Control Agents in Agriculture. Journal of Environmental Quality 38, 238-247.

Wheeler, A.P., Angermeier, P.L. and Rosenberger, A.E. (2005) Impacts of New Highways and Subsequent Landscape Urbanization on Stream Habitat and Biota. Reviews in Fisheries Science 13(3), 141-164.

Whitman, J.B., Zech, W.C. and Donald, W.N. (2019) Full-Scale Performance Evaluations of Innovative and Manufactured Sediment Barrier Practices. Transportation Research Record: Journal of the Transportation Research Board 2673(8), 284-297.

Whitman, J.B., Zech, W.C., Donald, W.N. and LaMondia, J.J. (2018) Full-Scale Performance Evaluations of Various Wire-Backed Nonwoven Silt Fence Installation Configurations. Transportation Research Record: Journal of the Transportation Research Board 2672(39), 68-78.

Wolman, M.G. and Schick, A.P. (1967) Effects of Construction on Fluvial Aediment, Urban and Suburban Areas of Maryland. Water Resources Research 3(2), 451-464.

Wood, P.J. and Armitage, P.D. (1997) Biological Effects of Fine Sediment in the Lotic Environment. Environmental Management 21(2), 203-217.

Figures

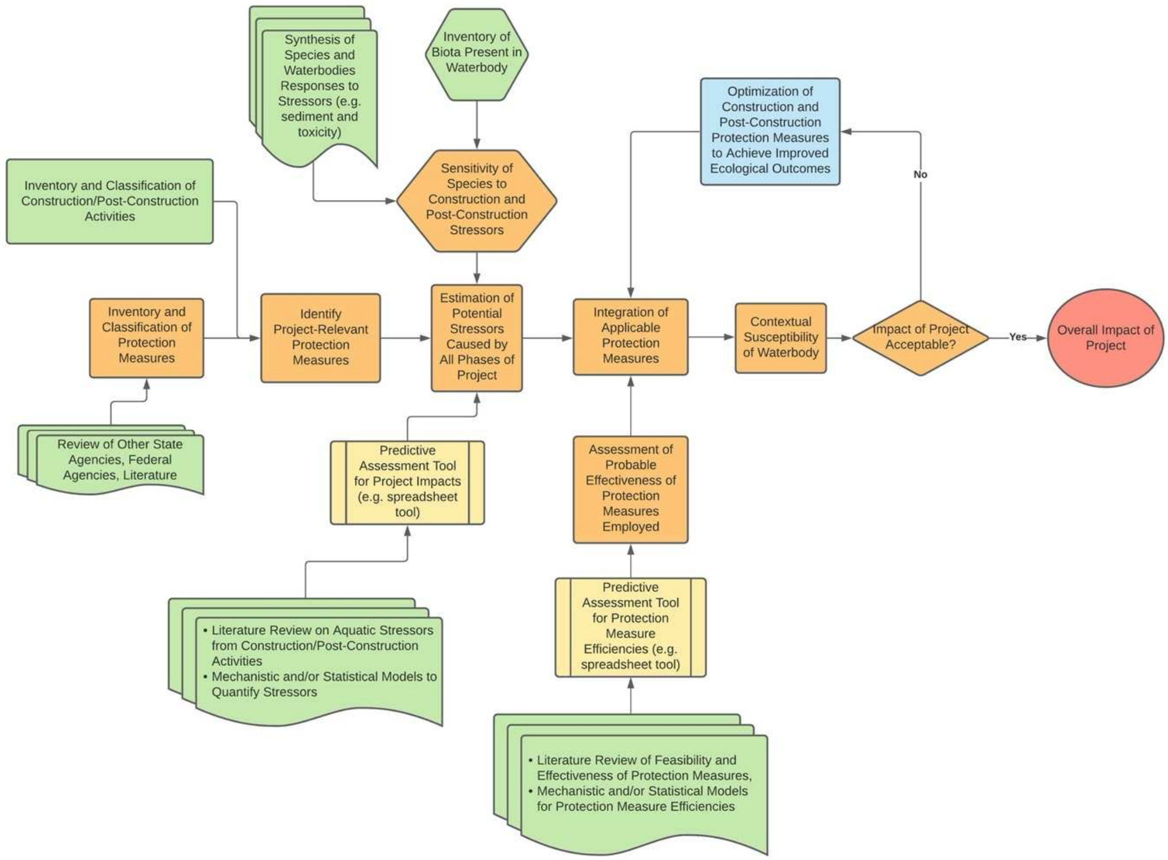

Figure 1: The general framework includes assessments, steps, processes, tools, and feedback loops to tailor protection measures to the contextual susceptibility of a waterbody. Analyses and classifications are developed as initial assessments to streamline framework steps and processes (green). These initial assessments are used as inputs within steps and processes of the framework (orange) as well as predictive scientific assessment tools (yellow) that quantify the impacts of stressors and attenuation provided by protection measures. Protection measures can be optimized through a feedback loop (blue) that uses thorough evaluations of alternative measures across both construction and post-construction phases to achieve improved ecological outcomes.

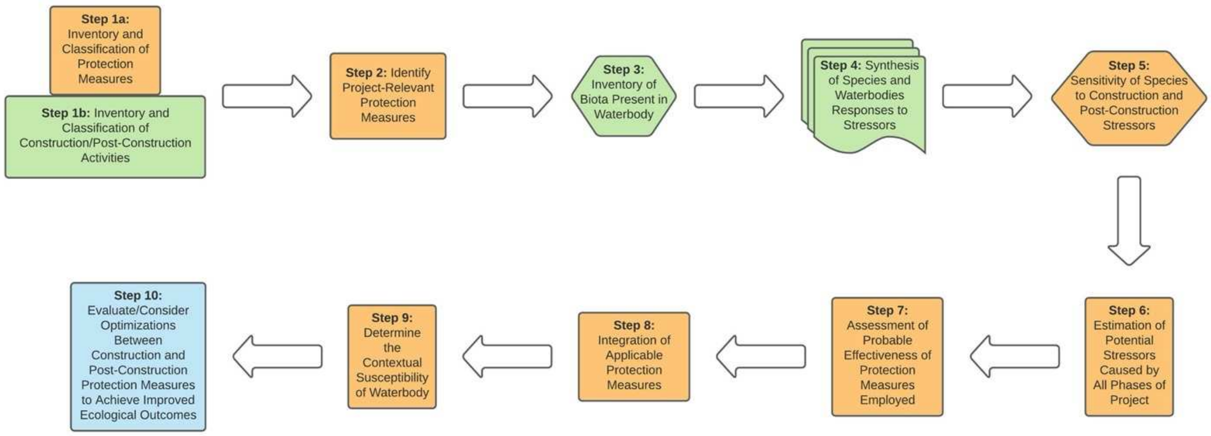

Figure 2: Flowchart of the steps from the general framework, including the same colors and symbols as Figure 1 for cross-referencing.

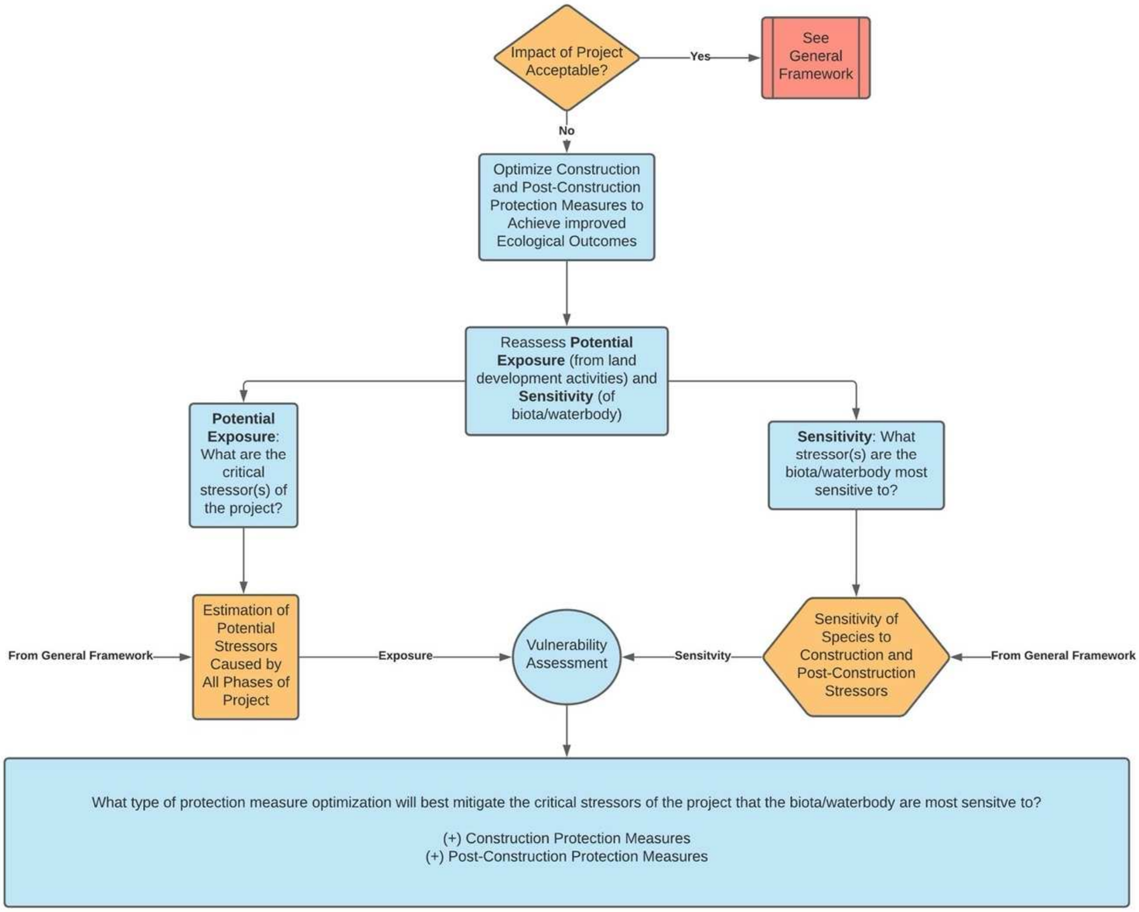

Figure 3: Outline of construction and post-construction protection measures for optimizations, an extension of the Step 10 in the general framework (Figure 1). This outline includes reiterative processes, highlighted in orange, from the general framework (Figure 1) estimating potential stressors and determining sensitivities of biota and waterbodies.

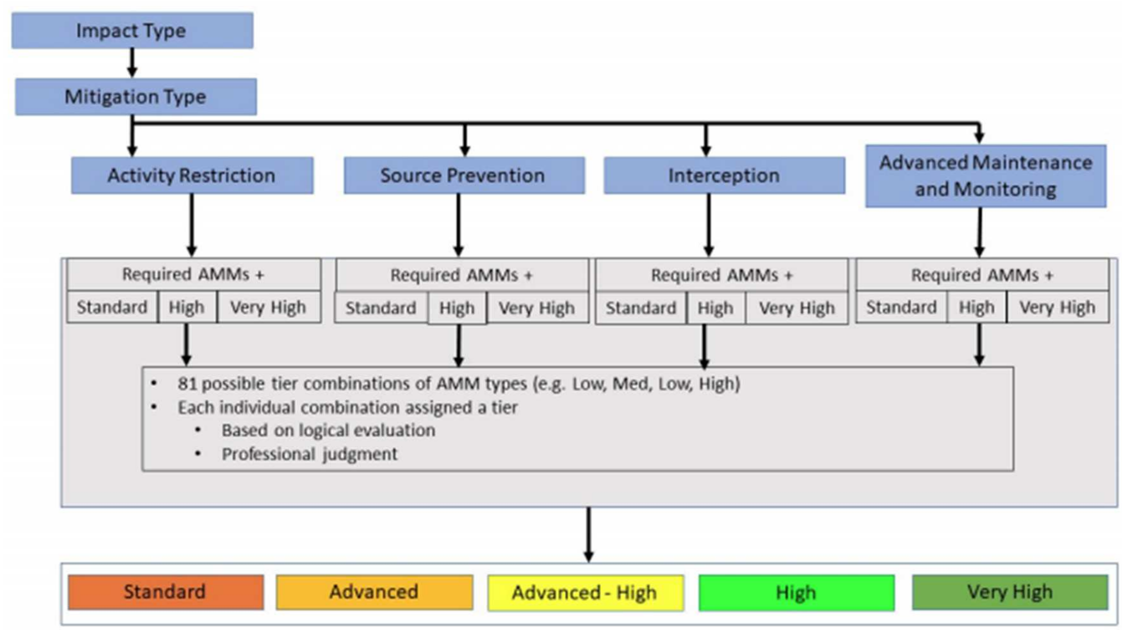

Figure 4: Final BMP level framework for the sediment effect score based upon eighty-one different possible tier combinations.

APPENDIX

INVENTORY OF UNIQUE AVOIDANCE, MINIMIZATION, AND MITIGATION MEASURES (AMMS)

#	AMM	State or Agency
1	Implement the following hydro-acoustic impact minimization measures for pile driving below bankfull elevation. i. Design or specify pile made of untreated wood, hollow steel, H-pile made of concrete, steel round pile or H-pile less than 36 inches in diameter in which both pile size and numbers of driven piles are minimized. ii. When practicable, use drilled shafts or a vibratory hammer for installing piles (i.e., avoid impact pile driving). iii. If concrete or steel pile must be installed by impact hammer, require that the Contractor prepare and implement a Noise Attenuation Plan (NAP) for review and approval by NMFS and/or USFWS. iv. The NAP must include a confined bubble curtain system, design details, performance testing, schedule, and a plan for monitoring and maintenance to achieve proper function. v. Only allow pile driving with an impact hammer between one hour after sunrise and one hour before sunset, regardless of the material type. This is to ensure that pile driving does not occur at dawn or dusk, the peak movement period for juvenile and adult ESA-listed fish. vi. In the event of an observance of any dead, injured, or distressed fish, collect the specimens if possible and immediately notify NMFS or USFWS, depending on species.	ODOT (Oregon)
2	If pumps are used, operate as needed to prevent de-watering of the stream downstream of diversion, monitor continuously, have a back-up pump in case of failure, maintain negative pressure inside work area to contain turbidity, and pump out significant sediment to filter through existing vegetation after completion of work	ODOT (Oregon)
3	Ensure structures meet stormwater management standards	ODOT (Oregon)
4	ODOT will ensure that fish passage, work area isolation, and containment are implemented as needed to protect aquatic and riparian habitat during replacement and repair activities	ODOT (Oregon)
5	Do not design or allow new temporary access roads within AH/NWZ unless no reasonable alternatives	ODOT (Oregon)

6	If night lighting is added to bridges over streams with listed fish, design it so it is directed toward roadway facilities, not habitat areas. Also restrict temporary construction lighting directed into habitat areas.	ODOT (Oregon)
7	Select and operate heavy equipment to minimize affects	ODOT (Oregon)
8	When practicable, ensure that painting, coating, or other chemical application occur at an approved off-site facility or area, as well as any other activities that have similar water quality effects	ODOT (Oregon)
9	Work area isolation and containment need to be implemented to protect aquatic and riparian habitats	ODOT (Oregon)
10	Any structures located below ordinary high-water elevation (OHWE) must avoid or minimize impacts or abrasion to prevent deposition of treated wood debris and dust into riparian or aquatic habitat	ODOT (Oregon)
11	Comply with in-water timing requirements/restrictions	ODOT (Oregon)
12	Structural cleaning: Pressure washing of structures shall be done using appropriate filter fabric to control and contain paint particles generated by the activity. Concentrated accumulations of bird feces and nests shall not be allowed to drop into the water. This material shall be scraped from the bridge structure and collected and disposed of at an appropriate upland location.	WSDOT (Washington)
13	Pressure washing of concrete structures shall be held to the minimum necessary to maintain structure integrity. (Pressure washing of concrete structures can result in an increased pH discharge with a potential to violate state water quality criteria.)	WSDOT (Washington)
14	Culvert cleaning and repair will occur during the dry season or when listed or proposed fish are not likely to be present	WSDOT (Washington)
15	Culvert cleaning will occur from the top of the bank as much as possible.	WSDOT (Washington)
16	Seasonal restrictions applied to work conducted below the ordinary high-water mark (OHWM) will be as required by a HPA issued by the Washington State Programmatic Biological Assessment January 2009 WSDOT Eastern Washington Regions Appendix C-4 Department of Fish and Wildlife, and Water Quality Standards for Surface Waters of the State of Washington (Chapter 173-201A WAC) and approved by USFWS	WSDOT (Washington)
17	All in-water work must comply with appropriate work windows as agreed upon by USFWS and WDFW.	WSDOT (Washington)
18	Concentrated accumulations of bird feces, road grit, sand, and loose paint chips will be removed as much as practicable from bridges before dismantling.	WSDOT (Washington)
19	All fish will be removed from the work area prior to any in-water work activities. Salmonid removal methods could include dewatering of salmonid habitat, netting of individuals, electrofishing, dispersal of salmonids through snorkeling or use of seine nets, and/or establishing a net enclosure around the	WSDOT (Washington)

	work area. Programmatic Biological Assessment January 2009 WSDOT Eastern Washington Regions Appendix C-6	
20	All equipment entering waters containing bull trout will use vegetable oil or other biodegradable, acceptable hydraulic fluid substitute	WSDOT (Washington)
21	Abrasive Blasting Containment: During abrasive blasting of a steel bridge prior to painting, a containment system appropriate for the type and location of the bridge shall be in place and maintained to prevent spent blast media from reaching Programmatic Biological Assessment January 2009 WSDOT Eastern Washington Regions Appendix C-6 state waters. Spent blast media shall be collected, sampled, and designated for its hazardous material content and disposed of as appropriate for its waste designation	WSDOT (Washington)
22	All concrete shall be poured in the dry, or within confined waters not being dewatered to surface waters, and shall be allowed to cure a minimum of seven (7) days before contact with surface water	WSDOT (Washington)
23	All dredged or excavated materials will be removed to an upland location where it cannot enter the waterbody.	WSDOT (Washington)
24	Water pumped from work isolation area will be filtered to remove suspended sediments prior to returning to the creek. Discharge will occur in such a manner as not to cause erosion. Programmatic Biological Assessment January 2009 WSDOT Eastern Washington Regions Appendix C-8	WSDOT (Washington)
25	No treated wood debris will be allowed to fall in the water. If any debris does fall in, it will be removed immediately	WSDOT (Washington)
26	All treated wood will be disposed of at an approved disposal facility for treated wood.	WSDOT (Washington)
27	The establishment and use of temporary access roads will meet the following conditions: 1. Activities will comply with hydraulic project approval requirements. 2. Existing roadways or travel paths will be used whenever reasonable. 3. Where stream crossings are essential, the crossing design will accommodate reasonably foreseeable risks (such as flooding and associated bedload and debris) to prevent diversion of stream flow out of the channel and down the road in the event of a crossing failure. 4. Vehicles and machinery must cross-riparian areas and streams perpendicular to the main channel wherever reasonable. 5. The number of stream crossings will be minimized.	WSDOT (Washington)
28	During subsurface sampling, when working off the highway, bridge deck, barge, or road surface, within 100 feet of waters containing listed fish species, a silt fence will be installed between the drilling site and waterbody to contain sediments and prevent sedimentation	WSDOT (Washington)
29	For brush and/or roller paint applications, painters shall work from pails containing a maximum of two (2) gallons of paint to minimize the impact of accidental spillage, except for sealed containers that are part of a spray system.	WSDOT (Washington)

30	Cleaning of paint materials and maintenance equipment shall not be done in waters nor shall resultant cleaning runoff be allowed to enter waters	WSDOT (Washington)
31	Drip pans or other protective devices shall be required for all paint mixing and solvent transfer operations	WSDOT (Washington)
32	Debris accumulations on the bridge, road surface, and within the bridge drains shall be collected or swept up and properly disposed of prior to fresh water flushing. Flushing will involve the use of clean water only, to prevent detergents or other cleaning agents from entering waters.	WSDOT (Washington)
33	All materials, such as riprap, placed within the water will be pre-washed to remove sediment and or other contaminants	WSDOT (Washington)
34	Round pile size is limited to less than or equal to 30 inches in diameter. H-pile size is limited to less than or equal to 14 inches.	MDOT (Maine)
35	Pile that are between 24 and 30 inches must have attenuated devices installed for all impact pile driving.	MDOT (Maine)
36	A vibratory hammer will be used as much as possible for all pile driving activities.	MDOT (Maine)
37	Pile driving will occur during the day when fish are less active and salmon migrations are minimized.	MDOT (Maine)
38	Hydroacoustic monitoring will be completed for all impact pile driving using the monitoring template developed by the Fisheries Hydroacoustic Working Group (FHWG) and following the methods described in the Technical Guidance (Caltrans 2015).	MDOT (Maine)
39	A bubble curtain meeting the design criteria, as defined in the User's Guide, will be employed during all impact pile driving events.	MDOT (Maine)
40	Sheet pile driving (if utilized) will be completed using a vibratory hammer	MDOT (Maine)
41	All bridge replacement AMMs also apply to temporary bridges and trestles.	MDOT (Maine)

42	To minimize fish stranding inside the cofferdam when dewatering, MaineDOT environmental staff or similarly qualified consultants will capture and remove as many Atlantic salmon and other fish species as possible. MaineDOT environmental staff or similarly qualified consultants will inspect the cofferdams after placement for presence of adult Atlantic salmon. If adult Atlantic salmon are observed during active construction, all activities will cease and MaineDOT environmental staff or similarly qualified consultants will immediately contact the USFWS Maine Field Office (207-866-3344). MaineDOT environmental staff or similarly qualified consultants will complete a fish evacuation where water depths allow following the plan found in Appendix A. As stated in Appendix A, nets will be used to "herd- fish out of the work area to the extent practicable prior to electrofishing and cofferdam installation. This kind of fish exclusion measure can occur prior to cofferdam construction when water depths are less than <2 feet. Appropriate fish evacuation techniques in cofferdams are required for bridge pier construction. Water depths and access make these evacuations a unique situation. In these cases, the Proponents will provide project-specific fish evacuation plans to the USFWS prior to programmatic approval.	MDOT (Maine)
43	All cofferdams will be fully removed from the stream immediately following completion of in-water work, minimizing delays due to high stream flows following heavy precipitation, so that fish and aquatic organism passage are not restricted any longer than necessary. If a project is not completed and there will be substantial delays in construction, cofferdams will be at least partially removed to allow passage of Atlantic salmon until construction resumes. All areas of temporary bottom disturbance will be restored to their original contour and character upon completion of the project.	MDOT (Maine)
44	All cofferdams will be removed using techniques to minimize turbidity releases. This includes allowing for the slow reintroduction of water into the work area and utilizing dirty water treatment systems for turbid water.	MDOT (Maine)
45	Temporary access roads placed in the riparian area will be constructed in a manner that they do not allow erosion into resources during the construction. This will be reviewed and approved as a part of the SEWPCP, including review of location as well as placing a non-erodible material on the surface of the road.	MDOT (Maine)
46	Temporary roads in stream channels will be constructed of non-erodible material, i.e., plain riprap or large riprap (per MaineDOT standard specs) over geotextile fabric.	MDOT (Maine)
47	Stone causeways will extend only to within 25 percent of the BFW of the stream/river.	MDOT (Maine)

48	All invert line and slipline projects analyzed as a part of this PBA will have fish passage measures included in the design. Fish passage measures include weirs inside and outside of the crossing structures to ensure that water depths and velocities allow for fish passage at a range of flows. Following past advices from the Services, the proponents recognize that fish passage measures will not aid in the recovery of Atlantic salmon. However, implementation of fish passage measures is still an important step to minimize the effects of these activities on Atlantic salmon as well as other fish species.	MDOT (Maine)
49	Invert line and slipline rehabilitation activities will not occur in Tier 1 priority areas. Invert line and slipline rehabilitation activities can occur in Tier 2 and Tier 3 priority areas. To aid in the recovery of Atlantic salmon, the Proponents will provide mitigation (CM #2) for invert line and slipline rehabilitation projects that occur in Tier 2 priority areas.	MDOT (Maine)
50	Suspended sediment treatment will follow procedures described in Section 3.4.2 "Dirty Water" Treatment System	MDOT (Maine)
51	Cable mats used for scour protection will be backfilled with gravel-like material between the voids. Any larger stones or streambed material excavated for the placement of the mats will then be distributed on top of the countermeasures.	MDOT (Maine)
52	No heavy construction equipment will travel into or through any flowing streams with erodible substrate (e.g., sand, silt, and clay). Travel of heavy construction equipment into or through flowing streams and on stream substrate will only occur when the stream substrate is non-erodible (e.g., ledge, cobble) and the contractor has received approval from MaineDOT environmental field office staff.	MDOT (Maine)
53	Permanent riprap placed in a stream below the bankfull elevation will be covered by ESM material.	MDOT (Maine)
54	Any riprap that is placed in a stream that is not within a cofferdam will be cleaned prior to placement.	MDOT (Maine)
55	No heavy equipment will be placed in the streams.	NCDOT (North Carolina)
56	For bridge construction projects on unpaved roads, additional measures emphasizing source control will be considered during design to reduce sediment deposition into the stream from the ongoing presence of the unpaved road. Such measures are intended to provide a conservation benefit and can offset impacts from the construction project itself. These measures can include paved approaches, paving to the top-of-the-hill, ditch blocks, sediment basins, and grassed swales. Reducing sedimentation provides a long term improvement to mussel habitat.	FLDOT (Florida)
57	For in-water substructure construction activities, weighted, floating turbidity barriers will be used around the work areas.	FLDOT (Florida)
58	All return water from groundwater dewatering will be discharged in accordance with the requirements from dewatering activities (E&SC Manual).	FLDOT (Florida)
59	In areas where the floodplain is low-lying and over twice as wide as the bridge opening, consideration should be given to include relief/equalizer culverts to	FLDOT (Florida)

	maintain the floodplain elevations within this waterway crossing. Additionally, the design should be prepared to ensure the overflow areas maintain connectivity to the main channel and prevent the potential for blocking fish passage as the flood flows recede from the floodplain overflow banks into the main channel.	
60	Culverts should be sufficiently sized and placed at the appropriate elevation to allow for the water depth, flow, and velocity that permit fish passage through the culverts.	FLDOT (Florida)
61	Culvert diameter (or box culvert width) should encompass 1.2 times the stream bankfull width to ensure the culvert is large enough to convey bankfull stream flow with minimal alteration of the stream's flow characteristics.	FLDOT (Florida)
62	Normal water levels should rise no higher than half the diameter of the pipe that is available above the bottom substrate.	FLDOT (Florida)
63	The culvert bottom should be counter sunk below the substrate to a minimum depth of six inches, regardless of the shape and size, to provide a sediment substrate conducive to fish passage.	FLDOT (Florida)
64	Culvert slope should be designed to match the existing channel grade within the roadway crossing. However, when the channel velocity exceeds the expected fish swimming speed, the channel slope should be regarded to protect the CH within the available state-owned right of way.	FLDOT (Florida)
65	Alternatives should be considered that preserved the stream's natural bottom for fish passage. One potential option is to consider the use of bottomless box culverts. Another alternative is the use of single span bridges, including Geosynthetic Reinforced Soil (GRS) bridge systems.	FLDOT (Florida)
66	Where possible, provide for bankfull flow with a single pipe or box culvert. Otherwise, install multiple pipe culverts or multi-cell box structures to minimize bankfull flow disruption. A bridge is preferable to multiple culverts.	FLDOT (Florida)
67	Perched culverts that form a barrier to fish passage during low flows should be prioritized for replacement.	FLDOT (Florida)
68	When the accumulation of sediment and debris in culverts exceed normal water levels and impede fish passage, these structures should be scheduled for maintenance activities as soon as possible. Culverts requiring frequent maintenance should be prioritized for either replacement or opening modifications to reduce the potential for clogging.	FLDOT (Florida)
69	Pier placement will be done in a manner that minimize changes in river flow patterns, reduces scour potential, and minimizes in-stream work areas. In addition, a minimal number of piers will be used.	PennDOT (Pennsylvania)
70	If there is a feasible alternative to dropping bridge components into the water, that alternative to dropping the bridge must be considered	PennDOT (Pennsylvania)
71	If there is no feasible alternative, document why the bridge must be dropped into the waterway. Minimize the overall stream impacts through removal of the existing bridge using successive deconstruction methods, including removal of asphalt wearing course, bridge deck, and non-critical trusses and members	PennDOT (Pennsylvania)

	when possible to minimize streambed disturbance that would result from a bridge collapse.	
72	Every bridge demolition will be accomplished by non-shattering methods. Shattering means any method which would scatter debris. Explosives and hoe-rams may be utilized in a manner that fractures, but does not shatter and scatter bridge components into the water.	PennDOT (Pennsylvania)
73	Scour holes, and holes remaining following pier removal, will be filled with natural cobble and gravel materials.	PennDOT (Pennsylvania)
74	Existing piers will be removed to below streambed level and allowed to refill with natural bed material to create potential habitat for endangered and threatened, unless such pier removal would increase the take of these mussels.	PennDOT (Pennsylvania)
75	Impacts to mussel communities and federally endangered mussels within the direct and indirect effect areas associated with the bridge project will be assessed, monitored and reported.	PennDOT (Pennsylvania)
76	Take of threatened and endangered mussels will be monitored and reported for bridge projects based upon anticipated populations in the disturbance area (footprint).	PennDOT (Pennsylvania)
77	When pumping to de-water cofferdams, drilled shafts, and other similar areas, the discharge shall be into an acceptable sediment containment bag or sediment containment area to minimize siltation in the water	PennDOT (Pennsylvania)
78	Alternative Service approved causeway/cofferdam technologies may be utilized. These technologies may not minimize the project footprint, but may minimize effects on mussel habitat by reducing the duration of causeway use, reduced scour effects, or result in reduced physical pressure to the river bed	PennDOT (Pennsylvania)
79	Runoff from the bridge deck will not be discharged directly to rivers or streams. It will be discharged onto level stone mats in front of the abutments, to grassed swales, or similar areas. This will reduce the likelihood of roadway contaminants and any accidental spills of hazardous materials from reaching rivers and streams.	PennDOT (Pennsylvania)
80	Use of rock fills and causeway areas will be minimized through the use of temporary bridges in the causeway. Gabion baskets (or equivalent) will be used to support the sides of the causeway and retain fill. Clean rock fill will be used for the causeway. Gabions and rock fill will be completely removed following completion of the new bridge.	PennDOT (Pennsylvania)
81	Construction activities within channels can occur during periods when water is absent from the channel. No discharge of water or spoil directly into the channel is allowed regardless of whether water is present. Upon completion of work activities, the stream bank/bed will be re?shaped to pre?disturbance condition. No flow modifications or disturbances in the channel are allowed when water is present. No work can occur in the channel if water is present	NDOR (Nebraska)

	without prior approval from NDOR Environmental and may require a re?initiation of consultation with resource agencies. The approval/disapproval may take up to 30 days. (Design, District, Contractor)	
82	If the pile driving is occurring during a time of year when ESA-listed species may be present, and the anticipated noise is above the behavioral noise threshold of those species, a 20 minute "soft start" is required to allow for animals to leave the project vicinity before sound pressure increases.	USACE (US Army Corps of Engineers)
83	Any new pile supported structure must involve the installation of less than or equal to 50 piles (below MHW).	USACE (US Army Corps of Engineers)
84	If the project involves steel piles, or non-steel piles> 24-inches in diameter, or any other noise-producing mechanism, the expected underwater noise (pressure) must be< the physiological/injury noise threshold for BSA-species in the action area.	USACE (US Army Corps of Engineers)
85	Work behind cofferdams, turbidity curtains, and other methods to block access of animals to dredge footprint is required when operationally feasible and ESA-listed species may be present.	USACE (US Army Corps of Engineers)
86	Only repair of existing discharge pipes allowed; no new construction.	USACE (US Army Corps of Engineers)
87	Direct temporary lighting away from suitable habitat during the active season.	FHWA (Federal Highway Administration)
88	Use downward-facing, full cut-off lens lights, and direct lighting away from suitable habitat when installing new or replacing existing permanent lights.	FHWA (Federal Highway Administration)
89	In most cases, hydroacoustic impacts will be addressed by requirements pursuant to the Endangered Species Act (ESA)	NMFS (National Marine

		Fisheries Service)
90	If ESA consultation is unnecessary for a project, vibratory hammers will be used to install/remove temporary and permanent piles, when/where possible.	NMFS (National Marine Fisheries Service)
91	If vibratory hammers are not practicable and impact hammers must be used, noise attenuation devices/methods may be employed for steel piles greater than 18-inches in diameter and concrete piles greater than 48-inches in diameter.	NMFS (National Marine Fisheries Service)
92	, one of the following methods may be used to give any animals the opportunity to leave an area prior to full-force pile driving.	NMFS (National Marine Fisheries Service)
93	“Ramp up” method (i.e., pile driving starts at a very low force and gradually builds up to full force),	NMFS (National Marine Fisheries Service)
94	"Dry firing” method (i.e., operating the pile hammer by dropping the hammer with no compression), or	NMFS (National Marine Fisheries Service)
95	“Soft start” method (i.e., noise from hammers is initiated for 15 seconds, followed by a 1-minute waiting period – this sequence is repeated multiple times).	NMFS (National Marine Fisheries Service)
96	pile installation (both in-water and “in the dry” [behind cofferdam]), will take place for a maximum of 18 hours per 24-hour period, to the maximum extent practicable.	NMFS (National Marine Fisheries Service)
97	silt or turbidity curtains will be used to reduce the impact of suspended sediments and potential for siltation/sedimentation of adjacent habitats	NMFS (National Marine Fisheries Service)
98	Piles will be placed in a way that does not impede the navigability of the waterway for species movement in the area.	NMFS (National Marine

		Fisheries Service)
99	Pile placement in rivers, streams or tidal creeks (including at the mouths4 of rivers, streams or tidal creeks) is limited to no more than 50% of the width of the waterbody.	NMFS (National Marine Fisheries Service)
100	Pile placement at the mouths of rivers, streams or tidal creeks is not authorized.	NMFS (National Marine Fisheries Service)
101	Pile placement in the main channels of rivers, streams or tidal creeks will be avoided; piles will be placed at the periphery of rivers, streams or tidal creeks, to the maximum extent practicable.	NMFS (National Marine Fisheries Service)
102	Water jetting will be avoided, to the maximum extent practicable, in areas with fine sediments	NMFS (National Marine Fisheries Service)
103	If jetting is necessary, silt curtains will be used.	NMFS (National Marine Fisheries Service)
104	Vibratory hammers should be used to remove piles.	NMFS (National Marine Fisheries Service)
105	Piles that cannot be removed with vibratory hammers, may be done with direct pull/clamshell methods.	NMFS (National Marine Fisheries Service)
106	If both methods are not practicable, piles will be cut off at or below the mud line.	NMFS (National Marine Fisheries Service)
107	In intertidal areas, piles will be installed/removed during low tide periods when sediments are exposed and work can proceed temporarily "in-the-dry," to the maximum extent practicable.	NMFS (National Marine

		Fisheries Service)
108	Installation of pile jackets, cathodic protection, and seismic retrofit components are authorized, provided there are only small increases (0.001 acre/jacket) in impact Projects will not appreciably change the bottom elevation (or water depth) of the area;area to the bottom (substrate).	NMFS (National Marine Fisheries Service)
109	Cofferdams and fills will be limited to no more than 50% of the width of the waterbody.	NMFS (National Marine Fisheries Service)
110	cofferdams are authorized in tidal creeks, temporary fills are not.	NMFS (National Marine Fisheries Service)
111	For temporary inflatable cofferdams, the footprints of the walls will be included into the overall impact area.	NMFS (National Marine Fisheries Service)
112	Steel sheet pile cofferdams will only be installed/removed with a vibratory hammer.	NMFS (National Marine Fisheries Service)
113	Minor dredging/underwater excavation is limited to -5.0 ft MLW and limited in size to 1000 ft^2 for a single and complete project.	NMFS (National Marine Fisheries Service)
114	Hydraulic dredging and knockdown/bed-leveling are not authorized.	NMFS (National Marine Fisheries Service)
115	Temporary work platforms/trestles are limited to 24 months or less, though extensions/exceptions can be coordinated with the NMFS on a case-by-case basis.	NMFS (National Marine Fisheries Service)
116	Temporary work platforms/trestles will be installed following the conservation measures in the Pile Installation and Removal section	NMFS (National Marine

		Fisheries Service)
117	New and replacement culverts will be sized to handle all expected/predicted flows, including low-flow conditions, normal flows, high flows, storm flows, and the full range of tidal flows.	NMFS (National Marine Fisheries Service)
118	Culverts will allow for normative physical processes within the stream-floodplain corridor by promoting natural sediment transport patterns, providing unaltered fluvial debris movement, and restoring or maintaining functional longitudinal continuity and connectivity of the stream-floodplain system.	NMFS (National Marine Fisheries Service)
119	Culverts may be replaced with small bridges.	NMFS (National Marine Fisheries Service)
120	Scour holes at culvert inlets/outlets will be repaired by placing the minimum amount of riprap necessary to mitigate the scour and no more than 0.5 acre for a single, complete project	NMFS (National Marine Fisheries Service)
121	May not exceed 2500 linear feet in length (for any type: e.g., seawalls, riprap, revetments) or 0.25 acre of tidally influenced estuarine/brackish areas, 0.1 acre of tidal freshwater areas, and 0.01 acre EFH-HAPC.	NMFS (National Marine Fisheries Service)
122	Full containment, such as diaper curtains, will be used when necessary, to avoid/eliminate any possible introductions of materials or chemicals.	NMFS (National Marine Fisheries Service)
123	new crossings/bridges with in- water structures (piers/piles/columns/footers) are not authorized.	NMFS (National Marine Fisheries Service)
124	Heavy equipment such as excavators, cranes, and bulldozers will not be located in the water to conduct work	NMFS (National Marine Fisheries Service)
125	buckets or extensions may reach into the water from atop the bank/platform/trestle to conduct work.	NMFS (National Marine

		Fisheries Service)
126	Maintenance projects are authorized, provided there is no introduction of debris, pollutants, toxicants, sediments, or other materials or chemicals into the waterbody.	NMFS (National Marine Fisheries Service)
127	Is only allowed in the previously authorized (permitted) footprint of the original/existing shoreline stabilization (i.e., no waterward extension or lateral expansion beyond the previous footprint).	NMFS (National Marine Fisheries Service)
128	All [water-dependent] activities are limited to 180 days or less ("temporary" is defined as 120 days or less), except temporary work platforms/trestles.	NMFS (National Marine Fisheries Service)
129	If geotextile fabric is not used, only rock rip-rap may be used for temporary fills.	NMFS (National Marine Fisheries Service)
130	Deck drains will not be allowed to discharge directly into the stream.	NCDOT (North Carolina)
131	Untreated stormwater collected from the bridge and associated roadways will not discharge directly into streams.	FLDOT (Florida)
132	Use downward-facing, full cut-off11 lens lights, and direct lighting away from suitable habitat when installing new or replacing existing permanent lights.	FHWA (Federal Highway Administration)
133	Drainage structures will be used on both sides of stream crossings to prevent road and ditch runoff from entering the stream.	PennDOT (Pennsylvania)
134	Treat or collect discharge water for drilling with 150 feet of habitat (or isolate)	ODOT (Oregon)
135	Specify if barges are allowed or not allowed	ODOT (Oregon)
136	IF barges allowed: i. Must be sufficient size and within safe load capacity to be stable during adverse conditions like severe storms, large waves	ODOT (Oregon)

	ii. Move if grounding at low tide is possible iii. Ensure barge and ballast are free of invasive species before bring it in iv. Load, secure, contain, stabilize, and maintain barge, materials, and equipment v. Dock barge in safe area if weather calls for unsafe condition that could case loss of stability, anchorage, or any reduction in safe load capacity	
137	For any replacement permanent stream crossing, notify how the bridge will not impair physical and biological processes associated with a fully function floodplain, and will restore those processes degraded by the previous crossing	ODOT (Oregon)
138	Design the stream crossing to maintain or restore floodplain function using the conditions	ODOT (Oregon)
139	If replacement or new bridge cannot provide basic goals of a floodplain, offset the functional equivalent of the area of the floodplain fill on-site or off-site where suitable protected lands are available (same sub-basin)	ODOT (Oregon)
140	During removal of bridge piles below the OHWE, in addition to standard pollution and erosion control measures (see Section 2.3.5) implement the following measures to minimize creosote release, sediment disturbance and total suspended solids: i. Install floating surface booms or other measures to capture floating surface debris. ii. Utilize methods to dislodge piles that minimize sediment disturbance. iii. Fill the holes left by each removed pile with clean, native sediments immediately upon removal. iv. For broken or intractable piling: • Do not excavate broken or intractable piles. • If a pile in uncontaminated sediment is intractable or breaks above or below the water surface, when feasible, cut off the pile or stump at least three feet below the surface of the sediment; cap with clean, native substrates that match surrounding streambed materials. •If a pile in contaminated sediment is intractable or breaks above the surface, when feasible, cut off the pile or stump at the sediment line. •If a pile breaks below the surface in contaminated sediment, make no further effort to remove it and cover the hole with a cap of clean substrate appropriate for the site. •If dredging is likely where broken piles are buried, use a GPS device to record the location of all broken piles for future use in site debris]characterization.	ODOT (Oregon)
141	Do not install trees or shrubs within 20 feet of roadway clear zone, bridges, culverts, behind guardrail, or adjacent to other permanent roadway structures	ODOT (Oregon)
142	No blasting in aquatic habitat supporting listed species below the OHWE	ODOT (Oregon)
143	Implement the following hydro-acoustic impact minimization measures for pile driving below bankfull elevation. i. Design or specify pile made of untreated wood, hollow steel, H-pile made of	ODOT (Oregon)

	concrete, steel round pile or H-pile less than 36 inches in diameter in which both pile size and numbers of driven piles are minimized. ii. When practicable, use drilled shafts or a vibratory hammer for installing piles (i.e., avoid impact pile driving). iii. If concrete or steel pile must be installed by impact hammer, require that the Contractor prepare and implement a Noise Attenuation Plan (NAP) for review and approval by NMFS and/or USFWS. iv. The NAP must include a confined bubble curtain system, design details, performance testing, schedule, and a plan for monitoring and maintenance to achieve proper function. v. Only allow pile driving with an impact hammer between one hour after sunrise and one hour before sunset, regardless of the material type. This is to ensure that pile driving does not occur at dawn or dusk, the peak movement period for juvenile and adult ESA-listed fish. vi. In the event of an observance of any dead, injured, or distressed fish, collect the specimens if possible and immediately notify NMFS or USFWS, depending on species.	
144	During bridge removal projects, as much of the existing structure as possible should be removed before finally dismantling the structure to limit the amount of material and debris from entering waters. This includes all roadbed material, decking, concrete curbs, etc.	WSDOT (Washington)
145	All bridge removal projects shall comply with water quality standards identified in the WSDOT – Washington State Department of Ecology Water Quality Implementing Agreement or approved Temporary Water Quality Modification Permit to maintain turbidity levels with approved standards and prevent degradation of water quality standards	WSDOT (Washington)
146	New stream crossing structures shall not reduce the existing stream width	WSDOT (Washington)
147	All in-water work on bridge replacement (>20') projects (and associated sub-activities, e.g., pier installation, temporary access installation, as necessary) will occur between July 15 and April 15.	MDOT (Maine)
148	In rearing habitat, bridge replacements with piers will not result in the net increase of structure footrprint.	MDOT (Maine)
149	In-water blasting is not allowed when Atlantic salmon could be present.	MDOT (Maine)
150	Bridges will be removed from the top down, first removing the asphalt with containment measures in place to prevent asphalt from dropping into the stream. The method of containment will be proposed by the contractor and approved by the project engineer. This will be followed by removal of the decking, girders, and finally the piles/shafts/columns.	NCDOT (North Carolina)

151	No new bents will be placed in the channel (unless justification is provided and then accepted by the Service).	NCDOT (North Carolina)
152	Existing abutments will be completely removed unless removal would result in destabilization of banks or increase adverse effects to listed mussels.	NCDOT (North Carolina)
153	a) Horizontal directional drilling pilot, entrance, and exit holes must be the minimum diameter necessary, and must be set back from the stream bank at least 50 feet. B) During horizontal directional drilling, excavated materials and drilling muds must be stockpiled on non-wetland areas, where available. Fabric must be placed beneath all materials stockpiled in wetlands.	FLDOT (Florida)
154	For new bridges and bridge replacement, design alternatives should be considered that avoid placement of hardened materials within the stream (support piles, rip rap). If structures cannot bridge the 100-year floodplain, floodplain drains should be considered to provide relief for stormwater and reduce the need to widen the stream's hydraulic opening by dredging or other means.	FLDOT (Florida)
155	When using barges during construction/demolition activities, they will be held in place with spuds and/or anchors to prevent bottom scour in shallow waters.	FLDOT (Florida)
156	When constructing new bridges, materials will be used that do not require maintenance, such as sand-blasting or painting.	PennDOT (Pennsylvania)
157	Conduct drilling through existing piers or utilize offsite borings and interpret.	PennDOT (Pennsylvania)
158	If there is no feasible alternative to in-stream disturbance, document this and utilize minimization measures to reduce in-stream impacts and substrate disturbance. Such measures include the use of barges, and minimizing the number of core borings	PennDOT (Pennsylvania)
159	No impacts will occur outside the construction footprint when performing geotechnical drilling.	PennDOT (Pennsylvania)
160	When project-related fence construction/relocation work is required to be done prior to the start of construction and if the fence work occurs outside urban or cropland areas not within swift fox or mountain plover range, then fencing can be installed/relocated at any time using the following criteria: a. the fencing is temporary in nature and/or consists of only hand-driven posts b. the work does not compact the soils (ex. through the use of heavy equipment) or cause soil disturbance beyond the driving of posts c. within the whooping crane migration corridor, work occurring within a half of a mile of wetlands or perennial waters will occur between the hours of 10:00 am to 4:00pm when the work is between March 10th to May 10th or	NDOR (Nebraska)

	September 16th to November 16th If the fencing work cannot meet these criteria, then NDOR Right-of-Way Division shall coordinate with NDOR environmental prior to the completion of Right-of-way negotiations.	
161	Direct temporary lighting away from suitable habitat during the active season.	TVA (Tennessee Valley Authority)
162	Evaluate the use of outdoor lighting during the active season and seek to minimize light pollution when installing new or replacing existing permanent lights by angling lights downward or via other light minimization measures (e.g., dimming, directed lighting, motion-sensitive lighting).	TVA (Tennessee Valley Authority)
163	No blasting will occur.	USACE (US Army Corps of Engineers)
164	Drilling will occur from existing structures (e.g., bridges, temporary work trestles), barges, vessels, or low ground bearing pressure tracked rigs.	NMFS (National Marine Fisheries Service)
165	Barge grounding is not authorized.	NMFS (National Marine Fisheries Service)
166	All areas will be restored to pre-drilling/pre-sampling conditions and elevations.	NMFS (National Marine Fisheries Service)
167	Shoreline stabilization for new bridges (approaches/causeway/embankment) will adhere to Shoreline Stabilization conservation measures	NMFS (National Marine Fisheries Service)
168	Bridge replacements on existing or parallel alignments are authorized, provided all unused portions of the old/existing structure are completely removed. Complete removal is preferred, though removing structures at or below the mud line is acceptable.	NMFS (National Marine Fisheries Service)

169	For bridge replacements on existing or parallel alignments, approach-fills no longer used due to modifications of the bridge design (e.g., lengthening) or fills not intended to be used for stormwater treatment, should be removed and graded to adjacent habitat levels, as determined through on-site surveys.	NMFS (National Marine Fisheries Service)
170	Construction and/or repairs to groins, jetties, breakwaters that are perpendicular to shore, and beach nourishment/re-nourishment are not authorized.	NMFS (National Marine Fisheries Service)
171	Must not extend any further waterward than 6 inches as measured from the mean high water line (MHWL) if located in tidally influenced areas.	NMFS (National Marine Fisheries Service)
172	Must not extend waterward from the MHWL is areas where oyster/shell habitat is present.	NMFS (National Marine Fisheries Service)
173	Must not extend waterward into tidal creek habitat.	NMFS (National Marine Fisheries Service)
174	Only confined blasts with stemmed charges will be used	NMFS (National Marine Fisheries Service)
175	blast mats will be employed to contain "fly rock."	NMFS (National Marine Fisheries Service)
176	Stormwater ponds will not discharge overflow directly into streams.	FLDOT (Florida)
177	Culvert replacement projects that will decrease the culvert size are not authorized.	NMFS (National Marine Fisheries Service)
178	Conduct habitat surveys of suitable cave, karst, or structure (e.g., building, bridge) within project boundaries based on the following criteria: o Survey can be conducted any time of year; results are valid for two years if a	TVA (Tennessee Valley

	bridge or other non-natural structure. o Survey can include on-site visits and/or review of aerial photos, maps, mining records, forest inventories, or previous surveys. o Applies to caves, sinkholes, karst fissures, quarries, mine portals, bridges o Applies to ground openings greater than one ft in diameter (and where feasible and where human safety is not at risk). o Applies to underground passages that continue beyond dark zone and do not end within 40 ft of entrance. o Entrances that are flooded or prone to flooding (i.e., debris on ceiling), collapsed, or otherwise inaccessible to bats are excluded. o Ground openings that have occurred recently (i.e., within the past 12 months) or suddenly appear (e.g., sinkholes) due to creation or subsidence are excluded. However, document site with written description and photographs of opening for reporting purposes.	Authority)
179	Herbicide use will be avoided within 200 ft of portals associated with caves, cave collapse areas, mines and sinkholes that are capable of supporting cave-associated species. Herbicides are not applied to surface water or wetlands unless specifically labeled for aquatic use. Filter and buffer strips will conform at least to federal and state regulations and any label requirements.	TVA (Tennessee Valley Authority)
180	Periodic Environmental Inspections observing construction activities (may affect species and critical habitat)	ODOT (Oregon)
181	Design structures to provide adult and juvenile fish passage when possible i. Or somewhere else in the subbasin	ODOT (Oregon)
182	No equipment crossing aquatic habitat with listed species directly for temp. access	ODOT (Oregon)
183	Only divert 10 percent if streamflow is needed for construction (with bypass systems and screens)	ODOT (Oregon)
184	Identify no work zones in plans and SPs to protect resources i. 3:1 replacement ratio for resources lost	ODOT (Oregon)
185	Only plan and designate them on undeveloped/undisturbed land if no alternative i. Keep them 150 feet from habitats or No Work Zones	ODOT (Oregon)
186	Do not discharge contaminated or sediment-laden water or water contained within a work isolation area directly into aquatic habitat/no work zone i. Unless it meets turbidity requirement of #3	ODOT (Oregon)
187	Turbidity levels measured 100ft downstream of site may not exceed 10% of readings 100ft upstream of site	ODOT (Oregon)
188	Prevent leaks and spills from vehicles and equipment i. Inspect and clean all within 150 feet of aquatic habitat/no work zone/storm inlet	ODOT (Oregon)

	ii. Areas for fueling, servicing, parking must be at least 150 feet from AH/NWZ iii. Maintain and protect stationary equipment 150 feet from AH/NWZ or storm inlet	
189	Treat all discharge from construction using best available technology applicable for the site	ODOT (Oregon)
190	Implement adequate containment areas to prevent pollutants or construction material from entering AH/NWZ	ODOT (Oregon)
191	Do not design or allow on steep slopes that will cause excessive erosion	ODOT (Oregon)
192	Restoration must remove all temp. access roads, stabilize soil, restore natural vegetation	ODOT (Oregon)
193	Do not design or allow the use of treated construction materials or those preserved with pesticide compounds unless no alternatives	ODOT (Oregon)
194	If treated materials are used over water or in-water, all surfaces exposed are to be waterproof sealed or barrier that is maintained during life of project	ODOT (Oregon)
195	For use of treated materials below OHWE: i.Store pesticide-treated wood in appropriate dry storage areas, at least 150 feet away from aquatic habitat supporting listed species or where it will not drain into such habitat. This distance may be modified based on site conditions and justified in the Project Notification (see Section 3.4.2). ii. Avoid contact with standing water and wet soil. iii.Ensure pesticide-treated wood is free of residue, bleeding of preservative, preservative-saturated sawdust, contaminated soil, or other pollutants. iv.Use prefabrication whenever practicable to minimize onsite cutting, drilling, and field preservative treatment. v.Do not discharge of sawdust, drill shavings, excess preservative and other debris into riparian or aquatic habitat	ODOT (Oregon)
196	For removal of treated wood over aquatic habitat supporting listed species, require that the Contractor develop a work containment plan (WCP) for the design and implementation of a work containment system (WCS) to avoid or minimize disturbance and potential release of construction debris, material, or other contaminants to riparian and aquatic habitat. Minimum design standards are: i. Not constructed of treated timber, unless implemented as per Measures 8-2 and 8-3. ii. Provides full containment of, and spill prevention for, hazardous liquids procedures iii. As applicable, is fire retardant or resistant to fire from welding slag, torch	ODOT (Oregon)

	operation, or any sparks from work. iv. Able to withstand dead load, live load, and wind loads	
197	Remove all when no longer needed, obliterate the route, and restore soils/natural vegetation	ODOT (Oregon)
198	Ensure that fish capture and removal is completed in work areas isolated from the active channel, except when infeasible in deep water situations or as recommended by the biologist.	ODOT (Oregon)
199	Biologists with current ODFW fish salvage permit must remove fish and aquatic life from the isolation work areas.	ODOT (Oregon)
200	Require that the Contractor allow fish biologists access into the isolation work areas as necessary.	ODOT (Oregon)
201	Any fish trapped within the isolated work area must be captured and released using a trap, seine, electrofishing, or other methods as prudent to minimize the risk of injury, before being released at a safe release site.	ODOT (Oregon)
202	If electrofishing is used to capture fish, NMFS electrofishing guidelines must be followed	ODOT (Oregon)
203	Develop a Temporary Water Management Plan and require that the Contractor update the plan as necessary for their construction methods. The Plan must meet pollution and erosion control requirements in this PBA and include at least the following information: i. The sequence and schedule for dewatering and re-watering. ii. Methods to isolate the work area from the active stream flow. iii. As applicable, methods to route and convey stream flow around or through the isolated work area. iv. As applicable, methods to de-water the isolated work area. v. As applicable, methods to pump and treat water before it is discharged downstream. vi. Specifications for on-site backup materials and equipment. vii. Calculations of water withdraw pumps capacity.	ODOT (Oregon)
204	Temp. Water Management maintains a downstream flow rate of 50% of upstream flow rate, and safe passage for adult and juvenile fish if it doesn't exist	ODOT (Oregon)
205	Minimize vegetation disturbance to greatest extent by leaving native materials where found, clip vegetation at ground level to retain root mass and encourage reestablishment, stockpile all large wood, native veg., topsoil, and native channel material displaced by construction during site prep if needed for later.	ODOT (Oregon)
206	No herbicides in the most conservative buffer areas (measured perpendicular to bankfull elevation for streams, upland boundary for wetlands, or upper bank for roadside ditches)	ODOT (Oregon)
207	Specify Weed Management Areas in project plans and SPs	ODOT (Oregon)

208	Liquid and granular forms of herbicides must be applied by broadcast spraying, spot spraying, or hand/selective spraying	ODOT (Oregon)
209	Limit treatments in habitat supporting aquatic species to no more than 2 acres above OHWE and .25 acres below OHWE, per project, once per year.	ODOT (Oregon)
210	Minimize disturbance to native vegetation and aquatic habitats by I. Utilizing hand clearing or other low-impact methods whenever practicable. II. Utilizing spot spraying for herbicide treatment whenever practicable. III. Avoiding boom or broadcast spraying when wind speeds exceed 5 miles per hour. IV. Keeping boom or spray as low as possible to reduce wind effects.	ODOT (Oregon)
211	Allow only these herbicides: I. quatic imazapyr (e.g., Habitat) II. aquatic glyphosate (e.g., AquaMaster, AquaPro) III. aquatic triclopyr-TEA (e.g., Renovate 3) IV. chlorsulfuron (e.g., Telar, Glean, Corsair) V. clopyralid (e.g., Transline) VI. glyphosate (e.g., Rodeo) VII. imazapic (e.g., Plateau) VIII. imazapyr (e.g., Arsenal, Chopper) IX. metsulfuron-methyl (e.g., Escort) X. picloram (e.g., Tordon) XI. sethoxydim (e.g., Poast, Vantage) XII. sulfometuron-methyl (e.g., Oust, Oust XP) XIII. triclopyr (e.g., Garlon 3A, Tahoe 3A)	ODOT (Oregon)
212	Hard armoring, unless replacing, below OHWE in listed habitat areas requires approval from NMFS or USFWS	ODOT (Oregon)
213	Design amount of hard armoring to the minimum necessary to protect the integrity of the structure	ODOT (Oregon)
214	Whenever practicable, use natural materials in stream bank stabilization or scour protection designs: vegetated riprap with large wood, partially spanning porous weir, woody plantings, herbaceous cover, coir logs, deformable soil reinforcement, engineered log jams, floodplain flow spreaders, floodplain roughness	ODOT (Oregon)
215	Design and install vegetated riprap with large wood meeting the following minimum standards: i. When practicable, use natural hard points, such as large, stable trees or rock outcrops, to begin or end the toe of the revetment. ii. Develop an irregular toe and bank line to increase roughness and habitat value. iii. Place larger sizes of rock at the toe of the slope and smaller sizes higher in the bank where the shear stress is generally lower. iv. Except where bridge cover would shade out plant growth, incorporate soil	ODOT (Oregon)

	and plantings above critical scour elevations to provide a better growing medium for plants. To facilitate and improve success, install soil and plantings during construction of riprap slopes. v. To improve plant growth, avoid using geotextile fabrics as filter behind the riprap whenever practicable. vi. Include large wood as an integral component to create roughness, pools and cover whenever practicable vi. Terrace slopes wherever practicable.	
216	Visually inspect the natural bank stabilization and vegetated riprap each year after installations during low flows. Evaluate loss of rock materials, survival rate of vegetation, anchoring success of large woody debris, and any channel changes since construction	ODOT (Oregon)
217	For removal and repair activities in or over aquatic habitat of listed species, require the contractor to develop a WCP for a WCS, as per AMM 8-6	ODOT (Oregon)
218	Design the stream crossing to maintain or restore floodplain function using the conditions i. Meeting NMFS fish passage criteria (NMFS 2008c or latest version) ii. Single span structures have structural fill that is 2.2 times as wide as the active channel width. iii. Provide the basic goals of a functional floodplain	ODOT (Oregon)
219	Ensure removal of all other artificial constrictions within the functional floodplain in project limits that are not a component of the final project design	ODOT (Oregon)
220	Design utility lines to avoid trenching through streams or floodways that support listed aquatic species by aerial lines or directional drilling, boring, or jacking that span the floodway. If trenching is necessary… i. Backfill trenches with native material and cap portions within streams with clean gravel suitable for fish use in the project area. ii. Align each crossing as perpendicular to the watercourse as possible, and for drilled, bored or jacked crossings, ensure that the utility line is below the total scour prism. iii. Return any large wood displaced by trenching or plowing to its original position (as nearly as possible)Restore habitat functions	ODOT (Oregon)
221	Develop a site restoration plan	ODOT (Oregon)
222	Goals for site restoration: i. Confine human and livestock disturbance to small areas necessary for access or other special management situations ii. Completely stabilize areas with signs of significant past erosion and bare soil spaces are small, well dispersed iii. Soil movement is absent or slight and local iv. Native woody and herbaceous vegetation are present and distributed around the site v. Plants have normal, vigorous growth form, and a high probability of	ODOT (Oregon)

	remaining vigorous, healthy and dominant over undesired competing vegetation. vi. Vegetation structure has rooting throughout the available soil profile. vii. Plant litter is well distributed and effective in protecting the soil with little or no litter accumulated against vegetation as a result of active sheet erosion ("litter dams"). viii. A continuous corridor of shrubs and trees appropriate to the site are present to provide shade and other habitat functions for the entire streambank. ix. Streambanks are stable, well vegetated, and protected at margins by roots that extend below baseflow elevation, or by coarse-grained alluvial debris	
223	Base species on pre-construction data or reference sites, differentiated among re-vegetation units as appropriate for slope and aspect, hydrology, and soils, and will include a range of successional stages (early, mid, and late) (following guidance in FHWA 2007). Locate reference site within the same watershed, ecoregion, or recovery zone (depending on species).	ODOT (Oregon)
224	Revegation seeding and planting must occur during the appropriate planting season	ODOT (Oregon)
225	Exclude livestock from restoration areas on agency-owned lands with wildlife-friendly fencing	ODOT (Oregon)
226	Measure revegetation success separately in each revegetation unit	ODOT (Oregon)
227	Annually monitor site restoration areas until site restoration goals are reached and success criteria is met using the following ODOT Biology Mitigation Monitoring standars (http://www.oregon.gov/HWY/GEOENVIRONMENTAL/biology_mon.shtml)	ODOT (Oregon)
228	Obtain review/approval from NMFS and/or USFWS for design and specs of the following activities: streambank restoration, fish passage restoration, off- and side-channel habitat restoration, set-back existing berms/dikes/levees, and water control structure removal	ODOT (Oregon)
229	Design and implementation of boulder placements must occur in stream reaches with intact, well vegetated riparian areas and stream beds with coarse gravel or larger sediments. Cross-sectional area of boulders may not exceed 25% of cross-sectional area of low flow channel or be installed to shift stream flow to a single flow pattern. No dumping boulders or permanent anchoring with rebar or cabling.	ODOT (Oregon)
230	Use NMFS fish passage criteria with step weir, fish ladder, or culvert replacement	ODOT (Oregon)
231	Include large wood in stream bank restoration actions to max extent possible.	ODOT (Oregon)

232	Large woody material design and implementation must use pieces that are intact, hard, and undecayed/partly decaying with untrimmed rootwads to provide habitat for fish. Can also reposition wood already in stream or suspended over for greater interaction with stream.	ODOT (Oregon)
233	If stormwater management criteria cannot be fully met on-site, offset the function equivalent of the contributing impervious area off-site when suitable protected lands are available.	ODOT (Oregon)
234	A Temporary Erosion and Sediment Control Site plan will be developed and implemented if a project requires clearing, vegetation removal, grading, ditching, filling, embankment compaction, or excavation. BMPs will be used to control sediments from all disturbing activities.	WSDOT (Washington)
235	A Spill Prevention, Control, and Countermeasure plan will meet standard specs to ensure all pollutants and products are controlled and contained i. Site Information: Identify general site information useful in construction planning, recognizing potential sources of spills, and identifying personnel responsible for managing and implementing the plan. 28 ii. Project Site Description: Identify staging, storage, maintenance, and refueling areas and their relationship to drainage pathways, waterways, and other sensitive areas. Specifically address: Contractor's equipment maintenance, refueling, and cleaning activities, the Contractor's on site storage areas for hazardous materials. iii. Spill Prevention and Containment: Identify spill prevention and containment methods to be used at each of the locations identified in B., above. iv. Spill Response: Outline spill response procedures including assessment of the hazard, securing spill response and personal protective equipment, containing and eliminating the spill source, and mitigation, removal and disposal of the material. v. Standby, On-Site, Material and Equipment: The plan shall identify the equipment and materials the Contractor will maintain on site to carry out the preventive and responsive measures for the items listed. vi. Reporting: The plan shall list all federal, state and local agency telephone numbers the Contractor must notify in the event of a spill. vii. Program Management: Identify site security measures, inspection procedures and personnel training procedures as they relate to spill prevention, containment, response, management and cleanup. viii. Preexisting Contamination: If preexisting contamination in the project area is described elsewhere in the plans or specifications, the SPCC plan shall indicate measures the Contractor will take to conduct work without allowing release or further spreading of the materials. ix. Attachments ? Site plan showing the locations identified in (1. B. and 1. 17 C.) noted previously. ? Spill and Incident Report Forms the Contractor will be using.	WSDOT (Washington)
236	No contractor staging areas will be allowed within 300 feet of any wetland, stream, river or drainage identified by the project biologist unless a site specific review is completed by the project biologist and indicates that no	WSDOT (Washington)

	impacts to the sensitive resource areas will occur due to topography or other factors	
237	Construction impacts will be confined to the minimum area necessary to complete the project.	WSDOT (Washington)
238	Boundaries of clearing limits associated with site access and construction will be flagged to prevent ground disturbance outside of the limits.	WSDOT (Washington)
239	Vegetation will only be grubbed from areas undergoing permanent alteration. No grubbing will occur in areas slated for temporary impacts.	WSDOT (Washington)
240	Disturbed areas shall be restored to pre-conditions. Complete restoration for projects involving vegetation removal may be delayed until native plantings can mature to pre-conditions. Endemic native plant species to the project area or region of the state where the activity is occurring will be used.	WSDOT (Washington)
241	Removal of riparian vegetation should be minimized to the greatest extent possible. Native riparian vegetation will be replanted where feasible. Vegetation restoration will be coordinated with USFWS	WSDOT (Washington)
242	For projects adding more than 150 square feet of new pollution generating impervious surface, water quality and quantity treatment will be provided if discharging to a bull trout waterbody.	WSDOT (Washington)
243	Report emergency actions to the Spokane Washington office of the USFWS within one workday where listed species are potentially present. Limit scope of actions in response to emergency to only those actions that are necessary to address immediate emergency	WSDOT (Washington)
244	When feasible on stream bank protection and slide repair projects, evaluate and implement fish habitat improvement measures by incorporating available large woody debris and boulders in the bank protection or repair design.	WSDOT (Washington)
245	Fisheries habitat restoration projects located in watersheds that contain listed or proposed species under USFWS jurisdiction will be evaluated in coordination with the USFWS for feasibility/suitability as appropriate restoration activities	WSDOT (Washington)
246	Temporary material storage piles will not be placed within the 100-year floodplain during the rainy season unless the following conditions are met: (1) storage does not occur when flooding is eminent; and (2) if storage piles consist of erosive material they are to be covered with plastic tarps (or similar) and surrounded with straw bales. Materials used within 12 hours of deposition will not be considered a temporary material storage pile.	WSDOT (Washington)
247	Before entering the water, all equipment shall be checked for leaks and cleaned free of any external petroleum products, hydraulic fluid, coolants, and other deleterious materials. Wash water shall not be discharged to any waterbody without pre-treatment to state water quality standards.	WSDOT (Washington)
248	During subsurface sampling within 100 feet of waters containing listed fish species, where practical, all materials removed from the test hole shall be removed from the site	WSDOT (Washington)

249	Oil absorbent pads shall be placed under the drill rig during subsurface sampling when within 100 feet of waters containing listed fish species, to catch and control spills	WSDOT (Washington)
250	For subsurface sampling within 100 feet of waters containing listed fish species, the team lead shall have a minimum of four hours erosion control, spill control and containment training.	WSDOT (Washington)
251	For subsurface sampling within 100 feet of waters containing listed fish species, all existing large woody debris will be left on site	WSDOT (Washington)
252	Installation of riprap and other materials will occur from the banks or outside the wetted perimeter as much as possible.	WSDOT (Washington)
253	CM-33 Projects will follow the "Integrated Streambank Protection Guidelines" as much as practicable. Link: https://wdfw.wa.gov/publications/00046/	WSDOT (Washington)
254	When practicable, all fueling and maintenance of equipment (except for large cranes) will occur more than 150 feet from the nearest wetland, ditches, flowing or standing water. Fueling large cranes, pile drivers and drill rigs over 300 feet away may not be practicable	WSDOT (Washington)
255	Work will not inhibit passage of any adult or juvenile salmonid species throughout the construction periods or after project completion	WSDOT (Washington)
256	Fill material shall be placed, not randomly dumped	WSDOT (Washington)
257	Temporary fills must be entirely removed and the site restored to pre-existing conditions	WSDOT (Washington)
258	In-water work for all activities other than bridge replacement and geotechnical sampling without temporary tresles in Tier 1 priority areas of Tier 2 priority areas where Atlantic salmon are expected to be present will be conducted during the low stream flow period (July 15 to October 1).	MDOT (Maine)
259	All areas of temporary waterway or wetland fill will be restored to their original contour and character upon completion of the project. Temporary fill includeds fill that received authorization and fill that mistakenly enters a resource (i.e., from slope faliures, accidental broken sandbag cofferdams).	MDOT (Maine)
260	All in-water excavation will be conducted within a cofferdam	MDOT (Maine)
261	All areas of disturbed soil will be mulched and seeded with an approved native or noninvasive herbaceous seed mix following construction and/or planted with native woody vegetation and trees appropriate during the first available planting season. In areas where there is little to no slope and erosion and invasive species establishment is unlikely, the native woody vegation on the site will be allowed to regenerate naturally.	MDOT (Maine)

262	Vegetation rootstock will only be removed in those areas that are subject to permanent impacts. Replanting will be completed as necessary and feasible, but may not be possible in certain situations, such as permanent impact areas, roadway clear zone, or adjacent to or under bridges.	MDOT (Maine)
263	To minimize the spread of noxious weeds into the riparian zone, all off-road equipment and vehicles operating from the existing open and maintained roads must be cleaned prior to entering the construction site to remove all soils, seeds, vegetation, or other debris that could contain seeds or reproductive portions of plants. All equipment will be inspected prior to off-loading to ensure that they are clean.	MDOT (Maine)
264	During construction, any distured soils will be temporary stabilized with BMPs, such as hay mulch, plastic sheeting, erosion control mix, or other appropriate BMPS. Disturbed areas with erodible soil can include, but are not limited to, temporary storage piles, access ways, partially constructed slopes, etc.	MDOT (Maine)
265	The Proponents will hold a pre-construction meeting for each project with appropriate Environmental Field Representatives, other MaineDOT or MTA staff, and construction crew or contractor(s) to review all procedures and requirements for avoiding and minimizing effects to Atlantic salmon and to emphasize the importance of these measures for protecting salmon and its critical habitat. THE USACE, FHWA, and USFWS staff will be notified and attend these meetings if practicable.	MDOT (Maine)
266	The proponents will not have any disturbance (turbidity, acoustic, direct effects) in spawning areas during spawning and egg incubation periods (Oct. 1-April 30).	MDOT (Maine)
267	The proponents will not temporarily affect spawning habitat without restoration.	MDOT (Maine)
268	No activities that disturb the substrate will be conducted in streams with clay substrates that include in-water work outside of a sealed cofferdam. This is due to the unpredictable nature of undesirable effects.	MDOT (Maine)
269	The Proponents will require any work being completed under this PBA to submit a SEWPCP for review and approval of MaineDOT staff prior to the start of work. The plan includes the review of the implementation of any AMMs proposed.	MDOT (Maine)
270	For activities requiring bypass pumping in streams, stabilization techniques (such as sheets of poly) will be used to protect the stream from scour caused by the high water velocity coming from the hose(s) at the downstream end.	MDOT (Maine)
271	Temporary bypass systems will utilize non-erosive techniques, such as pipe or a plastic-lined channel that will accommodate the predicted peak flow rate during construction. These are reviewed as part of the contractor's SEWPCP. Predicted peak flows are provided to the contractor in the bid documents; these values are derived from the USGS regression (USGS 2015).	MDOT (Maine)
272	Bypass pumps will be sized according to the expected flows during construction.	MDOT (Maine)

273	No equipment, materials, or machinery will be stored, cleaned, fueled, or repaired within any wetland or watercourse. All vehicle and equipment refueling activities will occur more than 100 feet from any water course and if not, all refueling areas will require fuel spill containment structures as per the SPCC Plan. Other construction equipment maintenance will be done at a location consistent with SPCC Plan and in a manner that avoids hazardous materials getting into the stream.	MDOT (Maine)
274	All pumps and generators will have appropriate spill containment structures and/or spill remediate materials available, such as absorbent pads.	MDOT (Maine)
275	All equipment used for in-stream work will be cleaned of external oil, grease, dirt, and mud such that turbid water does not drain to any wetland or watercourse. Any leaks or accumulations of these materials will be corrected before entering streams or areas that drain directly to streams or wetlands. All releases into surface waters or wetlands will be reported immediately to the appropriate regulatory body.	MDOT (Maine)
276	Any removed piling or other demolition material will be properly disposed of at a location in compliance with the applicable regulatory approvals.	MDOT (Maine)
277	All intake pumps within fish bearing streams will have a fish screen installed, operated, and maintained. To prevent Atlantic salmon juvenile entrainment related to water diversions, the contractor will use a screen on each pump intake large enough so that the approach velocity does not exceed 6.10 m/s (.20 ft/s). Square or round screen face openings are not to exceed 2.38 millimeters (3/32 inch) on a diagonal. Criteria for slotted face openings will not exceed 1.75 millimeters (1/16 inch) in the narrow direction. These screen criterial follow those indicated in NMFS (2008). Intake hoses will be regularly monitored while pumping to minimize adverse effects to Atlantic salmon.	MDOT (Maine)
278	See AMM 3 above -Temporary fills must be removed in their entirety after the work is completed.	MDOT (Maine)
279	The Proponents will employ the following procedure when completing grout bag repairs. 1. Apply the grout slurry at a rate of 2 cubic yards per hour to reduce the likelihood of elevated pH values downstream. 2. Turbidity curtains will be used when practicable (in flows less than or equal to 1 foot per second) to separate high pH water from the rest of the river. 3. An anti-washout admixture (AWA) will be mixed with the grout prior to application. 4. Grout will be piped into or behind grout bags.	MDOT (Maine)
280	As per Standard Specification 656.3.6 (e)), the contractor will not place uncured concrete directly into a water body. The contractor shall not wash tools, forms, or other items in or adjacent to a water body or wetland.	MDOT (Maine)
281	Prior to the release to a natural resource, any impounded water that has been in contact with concrete placed during construction must have a pH between 6.0 and 8.5, must be within on pH unit of the background pH level of the resource and must have a turbidity level no greater than the receiving resource. This requirement is applicable to concrete that is placed or spilled (inlcuidng	MDOT (Maine)

	leakage from forms) as well as indirect contact vial tools or equipment. Disposal or treatment of water not meeting release criteria shall be addressed in the SEWPCP. Discharging impounded water to the stream must take place in a manner that does not disturb the stream bottom or cause erosion. The Contractor shall be responsible for monitoring pH with a calibrated meter accurate to .1 units. A record of pH measurements shall be kept in the Environmental Field Representative's log. Concrete being placed as a seal in a cofferdam for bridge pier construction is considered "impounded water".	
282	Demolition and debris removal and disposal will comply with Section 202.03 of MaineDOT's Standard Specifications. The Contractor will contain all demolition debris, including debris from wearing surface removal, saw cut slurry, dust, etc., and will not allow it to discharge to any resource. The Contractor will dispose of the debris in accordance with the Maine Solid Waste Law (Title 38 M.R.S.A., Section 1301 et. seq.). The demolition plan, containment, and disposal of demolition debris will be addressed in the Contractor's SEWPCP.	MDOT (Maine)
283	The proponents will not affect Atlantic salmon adults sheltering in holding pools.	MDOT (Maine)
284	The contractor may perform clearing operations but not grubbing operations until immediately prior to beginning grading operations.	NCDOT (North Carolina)
285	Once grading operations begin in identified Environmentally Sensitive Areas, work shall progress in a continuous manner until complete.	NCDOT (North Carolina)
286	Erosion control devices shall be installed immediately following the clearing operation.	NCDOT (North Carolina)
287	Seeding and mulching shall be performed on the areas disturbed by construction immediately following final grade establishment	NCDOT (North Carolina)
288	Seeding and mulching shall be done in stages on cut and fill slopes that are greater than 20 feet in height measured along the slope or greater than two acres in area, whichever is less.	NCDOT (North Carolina)
289	Special sediment control fence (NCDOT Standard No. 1606.01) or a combination of special sediment control fence and standard silt fence will be installed between the top of the stream bank and bridge embankment. Once the disturbed areas of the project draining to these areas have been stabilized, the special sediment control fence and/or silt fence and all built up sediment adjacent to these devices will be removed to natural	NCDOT (North Carolina)

	ground and stabilized with a native grass mix.	
290	All appropriate sedimentation and erosion control measures, throughout the project limits, will be cleaned out when half full to ensure proper function of the measures.	NCDOT (North Carolina)
291	Coir fiber matting or clean riprap (underlain with geotextile) will be installed on the footprint of unclassified structure excavation near the streambanks.	NCDOT (North Carolina)
292	Embankment construction and grading shall be managed in such a manner as to prevent surface runoff/drainage from discharging untreated into the riparian buffer. All interim surfaces will be graded to drain to temporary erosion control devices. Temporary berms, ditches, etc. will be incorporated, as necessary, to treat runoff before discharging into the riparian buffer (as specified in NCDOT BMP manuals).	NCDOT (North Carolina)
293	For construction project activities that result in soil disturbance, the SWPPP and/or ECP will be strictly adhered to, including the installation, inspection, and maintenance of erosion control devices. These measures will be described in the SWPPP and/or ECP.	FLDOT (Florida)
294	Complete the installation of sediment control devices prior to the commencement of any earthwork.	FLDOT (Florida)
295	Inspect all silt fences immediately after each rainfall and at least daily during prolonged rainfall. Immediately correct any deficiencies.	FLDOT (Florida)
296	Remove all sediment deposits when the deposit reaches approximately 1/2 of the volume capacity of the silt fence.	FLDOT (Florida)
297	During Florida's primary rainy season (June through August) erosion control devices protecting streams will be inspected after every rain event.	FLDOT (Florida)
298	a) To prevent potential destabilization or collapse of stream banks, no grubbing (i.e removing vegetation using methods that include ground disturbance) will occur within a horizontal distance of 25 feet from a stream's bankfull elevation except where required for placement of physical structures and clear zones. b) Erosion control devices will be installed parallel to streams for their protection.	FLDOT (Florida)
299	a) Disturbed lands that will not be brought to final grade within seven (7) days or are likely to be re-disturbed will be stabilized by employing appropriate temporary stabilization practices in accordance with E&SC Manual when slopes are <1:4. b) Sod or another equivalent performing stabilization measure will be used for temporary stabilization when slopes are greater than or equal to 1:4. c) The ECP will identify the extent of the disturbed lands and temporary stabilization measures.	FLDOT (Florida)

300	When CMs 4 and 10 are required, they will be incorporated into the ECP. The ECP will be provided to the District Environmental Management Office for review.	FLDOT (Florida)
301	Soil or dredge spoils will be stockpiled in uplands > 300 feet from streams. Additional erosion control measures (e.g. double silt fence) will be used for soils that due to site constraints must be stockpiled within 300 feet of streams.	FLDOT (Florida)
302	Equipment staging and storage areas will be located in the previously disturbed locations to prevent addition site disturbance. Acceptable staging/storage locations include previously cleared areas lacking native groundcover, and areas with compacted soils, gravel, or pavement. The contractor's proposed staging/storage locations will be provided to the District Environmental Management Office for review and approval	FLDOT (Florida)
303	Mowing and vegetation maintenance activities will avoid work with heavy equipment within riparian wetlands. Tree trimming near bridges will be done with equipment located on the bridge or roadway whenever possible to avoid disturbing wetland soils.	FLDOT (Florida)
304	All potential toxic substances such as fuels, paints, solvents, lubricants, etc. will be mixed and stored within a containment site that is buffered (berms, vegetation, distance, etc.) from streams.	FLDOT (Florida)
305	All equipment to be used in, on, or over streams will be checked on a daily basis for leaks or spills, and will be clean of any external petroleum products, hydraulic fluid, coolants, or other injurious materials.	FLDOT (Florida)
306	Cleaning of equipment or materials within 300 feet of streams will include the following measures. All cleaning fluids will be collected and disposed of in accordance with manufacturer's directions. No paint or cleaning fluids will be allowed to contact the ground or enter streams. Any spilled paint or cleaning fluids will be contained, collected, and disposed of off-site.	FLDOT (Florida)
307	Within 300 feet of streams, fertilizers will not be used.	FLDOT (Florida)
308	Within 300 feet of streams, pesticides will not be broadcast sprayed. Application of pesticides may be spot-applied manually in accordance with manufacturer's directions.	FLDOT (Florida)
309	No equipment, concrete debris, paving materials, litter, demolition debris, or any other materials will be allowed to fall into or be placed into the streams. Methods for removing accidental deposition into waterways will be coordinated with the District Environmental Management Office.	FLDOT (Florida)
310	Construction waste/debris will be removed and disposed in accordance with FDOT specifications.	FLDOT (Florida)
311	Fuel transfer, vehicle maintenance, and staging areas for construction vehicles and equipment will be on appropriate work pads located at least 150 feet away from receiving waters or at a minimum, within a containment site with adequate buffering (berms, vegetation, etc.) from recieving waters.	PennDOT (Pennsylvania)

312	All construction vehicles and equipment used near waterways will be inspected daily to identify and control possible leakage of toxic materials, including fuels, lubricants, etc. If leakage is found, the fluids will be contained and removed immediately in accordance with applicable regulations and the equipment repaired prior to further use.	PennDOT (Pennsylvania)
313	All potential toxic substances such as fuels, paints, solvents, lubricants, etc. will be stored within a containment area with adequate buffering (berms, vegetation, distance, etc.) from streams. No description of what constitutes an adequate buffer was provided in the BA.	PennDOT (Pennsylvania)
314	Unpermitted discharges to waterways shall be reported to the PennDOT District Environmental Unit immediately upon discovery.	PennDOT (Pennsylvania)
315	Accumulated debris and construction waste will be stockpiled away from watercourses.	PennDOT (Pennsylvania)
316	Loose debris and road surface material piles will be removed from the work site promptly to eliminate possible scattering by rain or wind.	PennDOT (Pennsylvania)
317	Install key sediment control measures before site grading begins.	PennDOT (Pennsylvania)
318	Install temporary silt fences around each bridge approach and around the perimeter of the disturbed area of small drainages.	PennDOT (Pennsylvania)
319	Exposed stream banks and shorelines will be temporarily stabilized with indigenous vegetation or riprap immediately after the work in the exposed area is completed.	PennDOT (Pennsylvania)
320	Disturbed areas will be permanently stabilized within 7 days of reaching final grade, using rapid seed and mulch, and where necessary supplemented with additional topsoil, erosion control matting, rip rap or retaining walls.	PennDOT (Pennsylvania)
321	Sediment control fences will be used where volume of water exceeds capacity of geo-fabric silt fence.	PennDOT (Pennsylvania)
322	Stockpiled soil materials will be located away from the watercourse and properly contained by appropriate silt fencing around the entire perimeter.	PennDOT (Pennsylvania)

323	Silt ditches with check dams will be used adjacent to streams to intercept runoff or flow and/or to divert flow to a controlled outlet, along the project perimeter to minimize sediment loss, and along all fill slopes exceeding 3 feet in vertical height	PennDOT (Pennsylvania)
324	No clearing or grubbing will be done until immediately before other work is to begin. Soil exposure will be sequenced in controlled phases, with disturbance limited to areas intended to be worked within the next 21 days.	PennDOT (Pennsylvania)
325	Use of tracked and wheeled equipment will be restricted to the area along the shoreline, and avoid all work below the Ordinary High Water Mark (OHWM), except at necessary crossings.	PennDOT (Pennsylvania)
326	Sedimentation impacts will be minimized by strict adherence to E&S control plans, and by regular inspection and maintenance of all E&S measures immediately after all storms.	PennDOT (Pennsylvania)
327	All construction vehicles and equipment that enters the waterway will be washed and inspected for juvenile zebra mussels (and other potential invasive or exotic species) before entering another body of water.	PennDOT (Pennsylvania)
328	All equipment will be appropriately cleaned, disinfected and inspected for zebra mussel adults and veligers using accepted protocols. Evidence of the same will be provided.	PennDOT (Pennsylvania)
329	Contractors will be briefed on all environmental issues and commitments and will conduct daily inspections utilizing a Compliance Checklist to assure compliance.	PennDOT (Pennsylvania)
330	PennDOT will provide an inspector or project foreman proficient in erosion and sedimentation control, pollution prevention plan implementation, and other environmental issues related to bridge and roadway construction. This individual will conduct additional compliance inspections	PennDOT (Pennsylvania)
331	For all projects involving in-stream work, post-construction monitoring will be conducted to assess habitat restoration and removal of construction debris.	PennDOT (Pennsylvania)
332	Service approved new causeway/cofferdam technologies may be utilized that may not minimize footprint but might otherwise minimize effects on mussel habitat by reducing the duration of causeway use, reduced scour effects, or result in reduced physical pressure to the river bed. If used, the effectiveness of new construction technologies will be monitored using a Service approved protocol.	PennDOT (Pennsylvania)
333	Avoid access and impacts to the stream.	PennDOT (Pennsylvania)

334	The direct and indirect impact areas will be clearly delineated in the field to ensure that only planned activities occur in each area.	PennDOT (Pennsylvania)
335	Monitor the removal of all demolition debris from the waterway as well as from adjacent upland locations.	PennDOT (Pennsylvania)
336	The federal action agency and PennDOT will provide notification and instruction for contractors regarding the presence of endangered or threatened species and proper implementation of avoidance and minimization measures.	PennDOT (Pennsylvania)
337	The federal action agency and PennDOT will include language providing notification and required conditions related to endangered mussels in contracts.	PennDOT (Pennsylvania)
338	The federal action agency, PennDOT and their contractors will notify Service and PFBC regarding spills and sedimentation events that may result in take beyond that estimated in this biological opinion.	PennDOT (Pennsylvania)
339	Work platforms, causeways, and new piers will be placed in unsuitable mussel habitat or in areas of lowest mussel densities practicable.	PennDOT (Pennsylvania)
340	In-stream impacts and the use of causeways will be minimized by carrying out construction from existing structures, land, and/or barges to the extent feasible	PennDOT (Pennsylvania)
341	Timing Restrictions: a) Wherever possible, in-stream work will be limited to one construction season. B) If multiple projects are scheduled within the same season within the same sub-watershed, care will be taken so that the cumulative impacts from all the projects are considered.	PennDOT (Pennsylvania)
342	Construction material, rock fill, and debris will be removed from the streambed and the streambed will be restored to pre-construction grade.	PennDOT (Pennsylvania)
343	Take of endangered mussels will be minimized by salvaging and relocating the mussels to suitable habitat and/or an appropriate holding facility; or, provide a contribution to a Service approved mussel conservation fund	PennDOT (Pennsylvania)
344	Monitoring of the direct impact area (one monitoring event) will be detailed in an approved monitoring plan and conducted three to five years post-construction to assess re-colonization of mussel populations.	PennDOT (Pennsylvania)

345	Two monitoring events at each relocation site will be implemented to assess survival within the five-year period post-construction. Methods will be detailed in a Service and PFBC approved monitoring plan.	PennDOT (Pennsylvania)
346	Mussel surveys will be performed. If results indicate that threatened and endangered species population density is greater than 0.50 per square meter, then avoidance, minimization, and conservation measures indicated for Management Unit 1 will be applied. If the results indicate population densities of less than 0.50 per square meter, then measures described for Management Unit 2 will be applied.	PennDOT (Pennsylvania)
347	Fish habitat features such as deep pools, riffles, and woody debris will be avoided or restored post-construction.	PennDOT (Pennsylvania)
348	Emergent vegetation beds and habitat will be avoided or restored post-construction.	PennDOT (Pennsylvania)
349	If there is a change in the project scope, the project limits, or environmental commitments, the NDOR Environmental Section must be contacted to evaluate potential impacts prior to implementation. Environmental commitments are not subject to change without prior written approval from the Federal Highway Administration. (District Construction, Contractor)	NDOR (Nebraska)
350	Conservation conditions are to be fully implemented within the project boundaries as shown on the plans. (District Construction, Contractor)	NDOR (Nebraska)
351	Request for early construction starts must be coordinated by the Project Construction Engineer with NDOR Environmental for approval of early start to ensure avoidance of listed species sensitive lifecycle timeframes. Work in these timeframes will require approval from the Federal Highway Administration and could require consultation with the USFWS and NGPC. (District Construction, Contractor)	NDOR (Nebraska)
352	If federal or state listed species are observed during construction, contact NDOR Environmental. Contact NDOR Environmental for a reference of federal and state listed species. (NDOR Environmental, District Construction, Contractor)	NDOR (Nebraska)
353	Refueling will be conducted outside of those sensitive areas identified on the plans, in the contract, and/or marked in the field. (Contractor)	NDOR (Nebraska)
354	The following project activities shall, to the extent possible, be restricted to between the beginning and ending points (stationing, reference posts, mile markers, and/or sectiontownship? range references) of the project, within the right?of?way designated on the project plans: borrow sites, burn sites, construction debris waste disposal areas, concrete and asphalt plants, haul roads, stockpiling areas, staging areas, and material storage sites. Any project related activities that occur outside of these areas must be environmentally	NDOR (Nebraska)

	cleared/permitted with the Nebraska Game and Parks Commission as well as any other appropriate agencies by the contractor and those clearances/permits submitted to the District Construction Project Manager prior to the start of the above listed project activities. The contractor shall submit information such as an aerial photo showing the proposed activity site, a soil survey map with the location of the site, a plan-sheet or drawing showing the location and dimensions of the activity site, a minimum of 4 different ground photos showing the existing conditions at the proposed activity site, depth to ground water and depth of pit, and the "Platte River depletion status" of the site. The District Construction Project Manager will notify NDOR Environmental which will coordinate with FHWA for acceptance if needed. The contractor must receive notice of acceptance from NDOR, prior to starting the above listed project activities. These project activities cannot adversely affect state and/or federally listed species or designated critical habitat. (NDOR Environmental, District Construction, Contractor).	
355	Construction waste/debris will be disposed of in areas or a manner which will notadversely affect state and/or federally listed species and/or designated critical habitat. (Contractor)	NDOR (Nebraska)
356	All permanent seeding and plantings (excluding managed landscaped areas) shall use species and composition native to the project vicinity as shown in the Plan for the Roadside Environment. However, within the first 16 feet of the road shoulder, and within high erosion prone locations, tall fescue or perennial ryegrass may be used at minimal rates to provide quick groundcover to prevent erosion, unless state or federally listed threatened or endangered plants were identified in the project area during surveys. If listed plants were identified during survey, any seed mix requirements identified during resource agency consultations shall be used for the project. (NDOR Environmental)	NDOR (Nebraska)
357	Environmentally Sensitive Areas will be marked on the plans, in the field, or in the contract by NDOR Environmental for avoidance. (NDOR Environmental, District Construction)	NDOR (Nebraska)
358	If species surveys are required for this project, results will be sent by NDOR to the USFWS, NGPC, and if applicable COE. FHWA will be copied on submittals. (NDOR Environmental, District Construction)	NDOR (Nebraska)
359	For activities within suitable habitat for the listed plants where a NE determination is made, include the following mitigation measure: Asphalt plants and staging areas for construction supplies and Contractor's equipment shall be located in areas that are frequently disturbed such as, but not limited to, field entrances, crop fields, abandoned roadway, farmsteads and roads. If this is not possible, the contractor shall coordinate with NDOR Environmental with a site plan showing the desired staging/stockpile location(s), which will be sited in such a way as to avoid impacting protected species.	NDOR (Nebraska)
360	Any detention basin outlets will be designed such that it is stabilized to prevent streambank erosion and will not otherwise impact stream channel/bank. (Design, Contractor)	NDOR (Nebraska)

361	Bridge deck debris will be captured and/or contained to prevent material from entering the channel. (District, Contractor)	NDOR (Nebraska)
362	Any upland soil disturbances will be designed to avoid or minimize sedimentation. (Design, Contractor)	NDOR (Nebraska)
363	A qualified biologist will survey according to protocol no more than 10 days prior to construction. If no active den sites are found, then the project can proceed. If active den sites are found, NDOR Environmental Section will notify the District and will consult with the USFWS, NGPC, and FHWA. If species are present the District will notify the Contractor to stop work within 1/2 mile of the active den until NDOR Environmental completes consultation. (NDOR Environmental, District Construction, Contractor)	NDOR (Nebraska)
364	If work is confined to an area between the hinge-points of the roadway or bridge deck, work may proceed. If work is required off the bridge deck or roadway surface, a qualified biologist will survey according to protocol no more than 10 days prior to construction. If no active den sites are found, then the project can proceed. If active den sites are found, NDOR Environmental Section will notify the District and will consult with the USFWS, NGPC, and FHWA. If species are present the District will notify the Contractor to stop work within 1/2 mile of the active den until NDOR Environmental completes consultation. (NDOR Environmental, District Construction, Contractor)	NDOR (Nebraska)
365	Presence/absence survey will be completed by a qualified biologist in the wetted river channel prior to completion of the Process. If survey is negative, consultation is complete. If mussels are found NDOR Environmental will consult with the USFWS, NGPC, and FHWA. (NDOR Environmental)	NDOR (Nebraska)
366	Prior to use at the construction site, barges and any equipment that will be used in the water must be de-contaminated of invasive aquatic species according to protocol. (Contractor)	NDOR (Nebraska)
367	No discharge of water or spoil directly into the channel. (Contractor)	NDOR (Nebraska)
368	Disturb the smallest footprint possible.	NDDOT (North Dakota)
369	Reclaim disturbed areas upon project completion.	NDDOT (North Dakota)
370	Utilize downcast and/or shielded lighting.	NDDOT (North Dakota)
371	Implement a Storm Water Pollution Prevention Plan (SWPPP). Employ and maintain erosion control measures (i.e. fiber rolls, straw wattles, erosion mats, silt fence, and/or turbidity barriers, etc.) throughout the duration of a project and until vegetation is established.	NDDOT (North Dakota)

372	If required, implement a Spill Prevention Control and Countermeasure Plan (SPCC)	NDDOT (North Dakota)
373	Employ dust control measures.	NDDOT (North Dakota)
374	Spot-spray herbicides rather than broadcast application on invasive/noxious weeds	NDDOT (North Dakota)
375	In accordance with state and federal laws, properly contain and dispose of any contaminated materials discovered during construction activities.	NDDOT (North Dakota)
376	Employ mufflers on all combustion engines.	NDDOT (North Dakota)
377	Properly contain and dispose of garbage/trash generated as a result of construction activities	NDDOT (North Dakota)
378	The contractor will notify the Project engineer immediately in the event any threatened or endangered species is identified within one mile of the proposed action. The Project engineer will cease all construction activities, establish at least a 0.5 mile avoidance area, and immediately coordinate with the USFWS, FHWA, and NDDOT Environmental and Transportation Services. The contractor will not resume work within the avoidance area until the Project engineer has confirmed with the agencies that work may proceed (either species have left the area or approved minimization measures have been implemented)	NDDOT (North Dakota)
379	Fire breaks are used to define and limit burn scope.	TVA (Tennessee Valley Authority)
380	Site-specific conditions (e.g., acres burned, transport wind speed, mixing heights) are considered to ensure smoke is limited and adequately dispersed away from caves so that smoke does not enter cave or cave-like structures.	TVA (Tennessee Valley Authority)
381	Acreage is divided into smaller units to keep the amount of smoke at any one time or location to a minimum and reduce risk for smoke to enter caves	TVA (Tennessee Valley Authority)
382	Planned timing for prescribed burns minimally overlaps with time of potential occupancy by bats (See Table 3-3).). If burns need to be conducted during April and May, when there is some potential for bats to present on the landscape and more likely to enter torpor due to colder temperatures, burns	TVA (Tennessee Valley

	will only be conducted if the air temperature is 55° or greater, and preferably 60° or greater.	Authority)
383	Fire breaks are plowed immediately prior to burning, are plowed as shallow as possible and are kept to minimum to minimize sediment.	TVA (Tennessee Valley Authority)
384	Tractor-constructed fire lines are established greater than 200 ft from cave entrances. Existing logging roads and skid trails are used where feasible to minimize ground disturbance and generation of loose sediment.	TVA (Tennessee Valley Authority)
385	Burning will only occur if site specific conditions (e.g. acres burned, transport wind speed, mixing heights) can be modified to ensure that smoke is adequately dispersed away from caves or cave-like structures. This applies to prescribed burns and burn piles of woody vegetation.	TVA (Tennessee Valley Authority)
386	Brush piles will be burned a minimum of 0.25 mile from documented, known, or obvious caves or cave entrances and otherwise in the center of newly established ROW when proximity to caves on private land is unknown.	TVA (Tennessee Valley Authority)
387	A 0.25 mile buffer of undisturbed forest will be maintained around documented or known gray bat maternity and hibernation colony sites, documented or known Virginia big-eared bat maternity, bachelor, or winter colony sites, Indiana bat hibernation sites, and northern long-eared bat hibernation sites. Undisturbed forest is important for gray bats to regulate temperatures at the mouth of the cave, and provide cover for bats as they emerge from the cave. Prohibited activities within this buffer include cutting of overstory vegetation, construction of roads, trails or wildlife openings, and prescribed burning. Exceptions may be made for maintenance of existing roads and existing ROW, or where it is determined that the activity is compatible with species conservation and recovery (e.g., removal of invasive species).	TVA (Tennessee Valley Authority)
388	Tree removal within 100 ft of existing transmission ROWs will be limited to hazard trees as defined in Section 3-2.	TVA (Tennessee Valley Authority)
389	Requests for removal of hazard trees on or adjacent to TVA reservoir land are inspected by staff knowledgeable in identifying hazard trees per International Society of Arboriculture and TVA's checklist for hazard trees. Approval is limited to trees with a defined target.	TVA (Tennessee Valley Authority)
390	Transmission actions and activities will continue to Implement A Guide for Environmental Protection and Best Management Practices for Tennessee Valley Authority Construction and Maintenance Activities (Appendix O). This	TVA (Tennessee Valley

	focuses on control of sediment and pollutants, including herbicides. The following are key measures: o BMPs to minimize erosion and prevent/control water pollution in accordance with state-specific construction storm water permits. BMPS are designed to keep soil in place and aid in reducing risk of other pollutants reaching surface waters, wetlands and ground water. BMPs will undertake the following principles: ? Plan clearing, grading, and construction to minimize area and duration of soil exposure. ? Maintain existing vegetation wherever and whenever possible. ? Minimize disturbance of natural contours and drains. ? As much as practicable, operate on dry soils when they are least susceptible to structural damage and erosion. ? Limit vehicular and equipment traffic in disturbed areas. ? Keep equipment paths dispersed or designate single traffic flow paths with appropriate road BMPs to manage runoff. ? Divert runoff away from disturbed areas. ? Provide for dispersal of surface flow that carries sediment into undisturbed surface zones with high infiltration capacity and ground cover conditions. ? Prepare drainage ways and outlets to handle concentrated/increased runoff. ? Minimize length and steepness of slopes. Interrupt long slopes frequently. ? Keep runoff velocities low and/or check flows. ? Trap sediment on-site. ? Inspect/maintain control measures regularly and after significant rain. ? Re-vegetate and mulch disturbed areas as soon as practical. o Application of herbicide is in compliance with USEPA, state water quality standards, and state permits. Areas in which covered species are known to occur on existing transmission line ROW are depicted on referenced, applicable spreadsheets and include specific guidelines to follow for impact minimization or avoidance. During pre-job briefings, the ROW Forester will review the location of these resources with contractors and provide guidelines and expectations from TVA's BMP Manual (Appendix O). Herbicides labeled for aquatic use are utilized in and around wetlands, streams, and SMZs. Unless specifically labeled for aquatic use, measures are taken to keep herbicides from reaching streams whether by direct application or through runoff or flooding by surface water. Hand application of certain herbicides labeled for use within SMZs is used only selectively. o Specific guidelines regarding sensitive resources and buffer zones: ? Extra precaution (wider buffers) within SMZs is taken to protect stream banks and water quality for streams, springs, sinkholes, and surrounding habitat. ? BMPs are implemented to protect and enhance wetlands. Select use of equipment and seasonal clearing is conducted when needed for rare plants; construction activities are restricted in areas with identified rare plants. ? Standard requirements exist to avoid adverse impacts to caves, protected	Authorit y)

	animals, and unique and important habitat (e.g., protective buffers around caves, restricted herbicide use, seasonal clearing of suitable habitat).	
391	Operations involving chemical or fuel storage or resupply and vehicle servicing will be handled outside of SMZs and in such a manner as to prevent these items from reaching a watercourse. Earthen berms or other effective means are installed to protect the stream channel from direct surface runoff. Servicing will be done with care to avoid leakage, spillage, and subsequent stream, wetland, or ground water contamination. Oil waste, filters, and other litter will be collected and disposed of properly. Equipment servicing and chemical or fuel storage will be limited to locations greater than 300-ft from, sinkholes, fissures, or areas draining into known sinkholes, fissures, or other karst features.	TVA (Tennessee Valley Authority)
392	Power plant actions and activities will continue to implement standard environmental practices. These include: o BMPs in accordance with regulations: o Construction Site Protection Methods ? Sediment basin for runoff - used to trap sediments and temporarily detain runoff on larger construction sites ? Storm drain protection device ? Check dam to help slow down silt flow ? Silt fencing to reduce sediment movement o SWPP Control Strategies ? Minimize storm water contact with disturbed soils at construction site ? Protect disturbed soil areas from erosion ? Minimize sediment in storm water before discharge ? Prevent storm water contact with other pollutants ? A storm water permit may be required at construction sites (less than 1 ac) o Each site has a Spill Prevention and Control Countermeasures (SPCC) Plan. Several hundred pieces of equipment often are managed at the same time on power generation properties; goal is to minimize fuel and chemical use.	TVA (Tennessee Valley Authority)
393	Woody vegetation burn piles associated with transmission construction will be placed in the center of newly established ROWs to minimize wash into any nearby undocumented caves that might be on adjacent private property and thus outside the scope of field survey for confirmation. Brush piles will be burned a minimum of 0.25 miles from documented caves and otherwise in the center of newly established ROW when proximity to caves on private land is unknown.	TVA (Tennessee Valley Authority)
394	Section 26a permits and contracts associated with solar projects, economic development projects or land use projects include standards and conditions that include standard BMPs for sediment and contaminants as well as measures to avoid or minimize impacts to sensitive species or other resources consistent with applicable laws and Executive Orders.	TVA (Tennessee Valley Authority)
395	Clearing of vegetation within a 200-ft radius of documented caves will be limited to that conducted by hand or small machinery clearing only (e.g., chainsaws, bush-hog, mowers). This will protect potential recharge areas of	TVA (Tennessee Valley

	cave streams and other karst features that are connected hydrologically to caves	Authority)
396	Continue to implement a siting process for proposed actions by prospective economic development applicants. This includes the following measures: o Landscape-level review on front end to determine existing land use, property ownership, and presence of natural and cultural resources to site an action in a location that results in impact avoidance or minimization o Targeted use of sites that have been previously disturbed for use as economic development sites, laydown areas, substations, ROWs. o Screening of prospective economic development applicants that targets sites for which environmental due diligence has been completed o If potential impacts are identified, actions are modified to avoid impacts to the extent possible. o Project-specific habitat assessments are conducted as needed.	TVA (Tennessee Valley Authority)
397	Continue to manage invasive plants, including those protect high priority sites where plant invasions threaten rare species habitats (e.g., cave entrances): o Identify and prioritize distributions, rates and modes of population expansions, sources of introduction, and ecological significance of invasive species; o Identify and prioritize areas requiring invasive species control; o Eradicate known substantial seed sources of invasive plants; o Develop management alternatives, using native species, to prevent further introduction of non-native species; o Employ prescribed burning, manual removal, and chemical control as appropriate for managing invasive species.	TVA (Tennessee Valley Authority)
398	No work will individually or cumulatively have an adverse effect on ESA-listed species or designated critical habitat; no work will cause adverse modification or destruction to proposed critical habitat.	USACE (US Army Corps of Engineers)
399	Work will not change temperature, water flow, salinity, or dissolved oxygen levels.	USACE (US Army Corps of Engineers)
400	If it is possible for ESA-listed species to pass through the action area, a zone of passage with appropriate habitat for ESA-listed species (e.g., depth, water velocity, etc.) must be maintained (i.e., physical or biological stressors such as turbidity and sound pressure must not create barrier to passage).	USACE (US Army Corps of Engineers)
401	The project will not adversely impact any submerged aquatic vegetation (SAV).	USACE (US Army

		Corps of Engineers)
402	Only mechanical, cutterhead, and low volume hopper (e.g., CURRITUCK) dredges may be used.	USACE (US Army Corps of Engineers)
403	No new dredging in proposed or designated Atlantic sturgeon or Atlantic salmon critical habitat (maintenance dredging still must meet all other PDC). New dredging outside Atlantic sturgeon or salmon critical habitat is limited to one-time dredge events (e.g., burying a utility line) and minor (? 2 acres) expansions of areas already subject to maintenance dredging (e.g., marina/harbor expansion).	USACE (US Army Corps of Engineers)
404	Temporary intakes related to construction must be equipped with appropriate sized mesh screening (as determined by the our section 7 biologist and/or according to Chapter 11 of the NOAA Fisheries Anadromous Salmonid Passage Facility Design) and must not have greater than 0.5 feet per second (fps) intake velocities, to prevent impingement or entrainment of any ESA-listed species life stage.	USACE (US Army Corps of Engineers)
405	Any temporary discharges must meet state water quality standards; no discharges of toxic substances	USACE (US Army Corps of Engineers)
406	Shell on bottom <50 acres with maximum of 4 corner marker buoys;	USACE (US Army Corps of Engineers)
407	Cage on bottom with no loose floating lines <5 acres and minimal vertical lines (1 per string of cages, 4 corner marker buoys);	USACE (US Army Corps of Engineers)
408	Floating cages in <3 acres in waters and shallower than -10 feet MLL W with no loose lines and minimal vertical lines (1 per string of cages, 4 corner marker buoys);	USACE (US Army Corps of Engineers)

409	Floating upweller docks in >10 feet MLLW	USACE (US Army Corps of Engineers)
410	Any in-water lines, ropes, or chains must be made of materials and installed in a manner (properly spaced) to minimize the risk of entanglement by keeping lines taut or using methods to promote rigidity (e.g., sheathed or weighted lines that do not loop or entangle)	USACE (US Army Corps of Engineers)
411	No conversion of habitat type (soft bottom to hard, or vice versa) for aquaculture or reef creation.	USACE (US Army Corps of Engineers)
412	Speed limits below 10 knots for project vessels with buffers of 150 feet for all listed species (1,500 feet for right whales).	USACE (US Army Corps of Engineers)
413	While dredging, dredge buffers of300 feet in the vicinity of any listed species (1,500 feet for right whales), with speeds of 4 knots maximum.	USACE (US Army Corps of Engineers)
414	The number of project vessels must be limited to the greatest extent possible, as appropriate to size and scale of project	USACE (US Army Corps of Engineers)
415	A project must not result in the permanent net increase of commercial vessels (e.g., a ferry terminal). The permanent net increase in vessels resulting from a residential project (e.g., dock/float/pier) must not exceed two vessels	USACE (US Army Corps of Engineers)
416	Modify all phases/aspects of the project (e.g., temporary work areas, alignments) to the extent practicable to avoid tree removal in excess of what is required to implement the project safely	FHWA (Federal Highway

		Administ ration)
417	Ensure tree removal is limited to that specified in project plans. Install bright colored flagging/fencing prior to any tree clearing to ensure contractors stay within clearing limits. Ensure that contractors understand clearing limits and how they are marked in the field.	FHWA (Federal Highway Administ ration)
418	E&S control devices required to be installed prior to any clearing and grubbing activities, to the maximum extent practicable	NMFS (National Marine Fisheries Service)
419	E&S control devices, where clearing and grubbing is necessary to provide access and area for the installation of devices, to be installed immediately following the minimal amount of clearing and grubbing that is necessary	NMFS (National Marine Fisheries Service)
420	E&S control devices required on all project-related areas, including off-site use areas, staging areas, and in/around temporary access roads and other areas	NMFS (National Marine Fisheries Service)
421	E&S control devices should be regularly inspected for effectiveness and promptly repaired or replaced if deficient	NMFS (National Marine Fisheries Service)
422	E&S control devices should be removed immediately following project completion	NMFS (National Marine Fisheries Service)
423	silt/turbidity curtains is limited to no more than 50% of the width of a waterbody	NMFS (National Marine Fisheries Service)
424	Siltation control fence or other stationary measures must be placed, at a minimum, parallel to the shoreline and may not be placed waterward of the mean high water line (MHWL) or ordinary high water mark (OHWM).	NMFS (National Marine Fisheries Service)
425	Fencing will not be placed in the water, perpendicular from the shoreline extending outward into the water	NMFS (National Marine

		Fisheries Service)
426	limited to 0.25 acre of tidally influenced area impacts, not to include oyster/shell, and will adhere to other restrictions within this section	NMFS (National Marine Fisheries Service)
427	All areas must be restored to pre-construction conditions following construction	NMFS (National Marine Fisheries Service)
428	To the maximum extent practicable, staging areas should be located in upland areas and have appropriate temporary erosion, turbidity, and sediment controls, including, but not limited to stabilized construction exists/entrances and sediment control fence	NMFS (National Marine Fisheries Service)
429	Staging areas will not be located in active channels (e.g., streams, tidal creek creeks, or rivers) or open water areas and will not be located in tidal areas	NMFS (National Marine Fisheries Service)
430	staging areas will be setback a minimum of 15 feet from the OHWM and MHWL	NMFS (National Marine Fisheries Service)
431	To the maximum extent practicable, site preparation (e.g., earthwork, obstruction removal, etc.) will begin following installation of temporary erosion, turbidity, and sedimentation control measures, including perimeter sediment control fence	NMFS (National Marine Fisheries Service)
432	Riparian and shoreline clearing, grading, and preparing will be completed by hand or with construction machinery (e.g., mini-excavator or bobcat/skid-steer); whichever method best avoids and minimizes erosion, sedimentation, and turbidity.	NMFS (National Marine Fisheries Service)
433	Construction machinery may not be located in an active channel or below the MHWL or OHWM for site preparation purposes.	NMFS (National Marine Fisheries Service)
434	Machinery may be placed atop work structures, such as work trestles, mats, or barges.	NMFS (National Marine

		Fisheries Service)
435	Riparian and shoreline vegetation will not be cleared, trimmed, or otherwise altered if the area is not essential for project construction or facilitation of construction.	NMFS (National Marine Fisheries Service)
436	No later than 24 months from initial installation, or upon completion of data acquisition, whichever comes first, the measuring device and any other structure or fill associated with that device (e.g., anchors, buoys, lines) must be removed and the site must be restored to pre- construction elevations.	NMFS (National Marine Fisheries Service)
437	Placement of geotextile barriers is required prior to placement of the temporary access fills to ensure that the fill will be removed completely at the end of construction.	NMFS (National Marine Fisheries Service)
438	Geotextile fabric may not be practical in dynamic systems and could actually do more harm than good if the fabric becomes detached or is swept away (e.g., they could entrap pelagic organisms). For this reason, this CM can be waived if it is determined that the use of the fabric will have an adverse effect on the species.	NMFS (National Marine Fisheries Service)
439	Temporary fill materials must be placed in a manner that will not be eroded/displaced by high water flows.	NMFS (National Marine Fisheries Service)
440	Temporary fills must be removed in their entirety and the affected areas returned to pre-construction conditions/elevations.	NMFS (National Marine Fisheries Service)
441	The navigability of the waterway will remain uninterrupted and freely open for species movement in/out of project work areas.	NMFS (National Marine Fisheries Service)
442	Appropriate measures must be taken to maintain normal downstream flows and minimize flooding to the maximum extent practicable	NMFS (National Marine Fisheries Service)
443	All spoil material must be placed in an approved upland disposal site, EPA-designated open water disposal site, USACE Dredged Material Management Area, or USACE approved beneficial use sites for mitigation or restoration and	NMFS (National Marine

	will employ erosion control measures such as upland erosion control or in-water turbidity curtains	Fisheries Service)
444	Equipment will only be used for its primary/intended purpose.	NMFS (National Marine Fisheries Service)
445	All equipment will be checked daily for leaks; 1 spill kit will be readily available on the project site at all times.	NMFS (National Marine Fisheries Service)
446	Equipment will not be used until leaks, or other maintenance issues, are repaired or new equipment is brought in for replacement.	NMFS (National Marine Fisheries Service)
447	To the maximum extent practicable, all equipment maintenance and other work that may release pollutants/toxicants will occur in contained maintenance areas at least 500 feet (preferred) from any water body and be outside of active stream channels, outside of any tidal areas, and away from ditches or channels that enter flowing waters.	NMFS (National Marine Fisheries Service)
448	Projects will not impede or restrict normal flows in/out of tidally influenced areas	NMFS (National Marine Fisheries Service)
449	Projects are not authorized if they contribute sediments, toxicants, or pollutants into areas tidally influence areas	NMFS (National Marine Fisheries Service)
450	Projects will use stormwater collection and treatment systems that discharge stormwater that meets or exceeds State Water Quality Standards into tidally influenced areas.	NMFS (National Marine Fisheries Service)
451	Approach/causeway fill will not be placed in tidal creek habitat or oyster/shell habitat, or restrict/impede normal flows in/out of tidally influenced areas.	NMFS (National Marine Fisheries Service)
452	Take-off/causeway fill for piers will not be placed in tidal creek habitat or oyster/shell habitat, or restrict/impede normal flows in/out of tidally influenced.	NMFS (National Marine

		Fisheries Service)
453	Scour repair projects are limited to the minimum amount necessary to achieve the project goal, which includes (1) the area of previously authorized scour protection (e.g., original footprint of previously authorized riprap around columns/piers/piles)	NMFS (National Marine Fisheries Service)
454	Scour repair projects are limited to the minimum amount necessary to achieve the project goal, which includes (2) 0.5 acre of new riprap for scour protection (typically upstream or adjacent to columns/piers/piles)	NMFS (National Marine Fisheries Service)
455	Total scour protection (new + previously authorized) will not exceed 0.5 acre (or 0.01 acre of oyster/shell habitat).	NMFS (National Marine Fisheries Service)
456	Scour holes at the base of bridge piers or abutments will be repaired by placing the minimum amount of riprap necessary to mitigate the scour.	NMFS (National Marine Fisheries Service)
457	Scour repair projects will not use poured concrete, reinforced concrete, or concrete mattresses for scour protection outside of the originally authorized project footprint.	NMFS (National Marine Fisheries Service)
458	Only riprap will be used for scour protection outside of the originally authorized project footprint.	NMFS (National Marine Fisheries Service)
459	Projects will not appreciably change the bottom elevation (or water depth) of the area;	NMFS (National Marine Fisheries Service)
460	riprap (or other scour protection) may be placed at a maximum 2 feet above the original bottom of the waterbody.	NMFS (National Marine Fisheries Service)
461	Channel width, depth, velocity, and slope that provide upstream and downstream passage of aquatic organisms will be preserved or enhanced according to current NMFS criteria or as developed in cooperation with NMFS to accommodate site-specific conditions	NMFS (National Marine

		Fisheries Service)
462	Must not extend more than 2.5 feet waterward of the MHWL (including the toe) in tidally influenced areas	NMFS (National Marine Fisheries Service)
463	must not extend more than 3 feet below the MHWL or OHWM	NMFS (National Marine Fisheries Service)
464	Shoreline stabilization materials must be free of debris and are limited to sand cement, concrete, and quarry stone.	NMFS (National Marine Fisheries Service)
465	Slope paving, poured concrete, or reinforced concrete is not authorized.	NMFS (National Marine Fisheries Service)
466	Removal of any length of shoreline stabilization (e.g., seawall, riprap) is allowed, provided the shoreline is stabilized.	NMFS (National Marine Fisheries Service)
467	Placement of backfill is authorized if it is necessary for stabilization/leveling	NMFS (National Marine Fisheries Service)
468	If banks are not available with suitable credits or in the appropriate service area, in-kind, permittee responsible mitigation will be undertaken with assistance from SERO HCD as close to the project as practicable.	NMFS (National Marine Fisheries Service)
469	Compensatory mitigation for unavoidable impacts to tidal freshwater areas and areas where anadromous fish occur will be offset by purchase of credits from a mitigation bank with suitable credits in the primary or secondary service area of the bank.	NMFS (National Marine Fisheries Service)
470	If banks are not available with suitable credits, FHWA/DOTs may purchase credits from a bank in the same watershed as the impact site at a 2:1 ratio, to adjust for out-of-kind mitigation.	NMFS (National Marine

		Fisheries Service)
471	Restoration activities, such as removing old bridge fills and restoring elevations to those found in nearby wetlands or shorelines may provide the necessary mitigation.	NMFS (National Marine Fisheries Service)
472	Erosion, turbidity, and sedimentation control measures will be used throughout construction to control erosion, turbidity, and sedimentation to ensure there are no violations of state or federal water quality standards.	NMFS (National Marine Fisheries Service)
473	Control measures will be monitored to (1) ensure species are not entangled or trapped in the project area,	NMFS (National Marine Fisheries Service)
474	Control measures will be monitored to (2) will be removed promptly upon project completion and the return of ambient water quality conditions	NMFS (National Marine Fisheries Service)
475	Control measures will be monitored to (3) and will not appreciably block entry to or exit from habitats.	NMFS (National Marine Fisheries Service)
476	Siltation barriers will be made of material in which listed species cannot become entangled (i.e., reinforced impermeable polycarbonate vinyl fabric [PVC]).	NMFS (National Marine Fisheries Service)
477	Turbidity curtains may not be practical in dynamic systems such as surf zones and could actually do more harm than good if the curtains become detached (e.g., they could entrap pelagic organisms). For this reason, this CM can be waived if it is determined that the use of the turbidity barrier will have an adverse effect on the species or when noted in the activity-specific PDCs below.	NMFS (National Marine Fisheries Service)
478	Petroleum products, chemicals, live (uncured) concrete, or water contaminated by these will not be allowed to enter flowing waters	NMFS (National Marine Fisheries Service)
479	To the maximum extent practicable, refueling will be done at least 250 feet from any water body and be outside of active stream channels, outside of any tidal areas, and away from ditches or channels that enter flowing waters;	NMFS (National Marine

	designated refueling sites in upland areas at least 250 feet away from receiving waters is preferred.	Fisheries Service)
480	Refueling of boats and heavy machinery such as cranes positioned atop temporary work platforms over the water will take all relevant precautions to avoid spills into waterbodies.	NMFS (National Marine Fisheries Service)
481	To the maximum extent practicable, concrete washout pits/pans/pools will be located at least 500 feet from any water body and be outside of active stream channels, outside of any tidal areas, and away from ditches or channels that enter flowing waters; designated sites in upland areas at least 500 feet away from receiving waters are preferred.	NMFS (National Marine Fisheries Service)
482	A Spill Plan will be created, and the Plan and all materials necessary to implement the plan will be accessible on site.	NMFS (National Marine Fisheries Service)
483	Construction personnel will ensure all materials placed in the water, including sheet piles, concrete piles, and erosion control materials, will be free of sediments and/or contaminants.	NMFS (National Marine Fisheries Service)
484	All over-water structures will incorporate measures to increase ambient light transmission and reduce shading.	NMFS (National Marine Fisheries Service)
485	All projects will incorporate measures to minimize permanent fill.	NMFS (National Marine Fisheries Service)
486	Temporary fills will not be used when other methods are available to facilitate construction, such as temporary work trestles, timber/crane mats, and floating barges.	NMFS (National Marine Fisheries Service)
487	To the maximum extent practicable, the placement of timber/crane mats in salt marsh habitat should be limited to 6 months (180 days) for a given location and barge grounding should be minimized.	NMFS (National Marine Fisheries Service)
488	Earthen fill of any kind (temporary or permanent) is not authorized in tidal creek habitat.	NMFS (National Marine

		Fisheries Service)
489	Impacts to oyster/shell habitat and will be limited to 0.01 acre for a single and complete project.	NMFS (National Marine Fisheries Service)
490	Oyster/shell that will be impacted by a proposed project (e.g., through fill activities) will be relocated with the assistance of SERO HCD and State Natural Resource agencies.	NMFS (National Marine Fisheries Service)
491	Impacts to submerged aquatic vegetation/seagrasses, coastal inlets, all state-designated nursery habitats of particular importance to shrimp and snapper-grouper, state-identified overwintering areas for shrimp, and marine areas will not occur.	NMFS (National Marine Fisheries Service)
492	Projects and activities will not meaningfully impede or obstruct passage of species.	NMFS (National Marine Fisheries Service)
493	All temporary work areas, modified or disturbed portions of streams, banks, and riparian areas will be restored to pre-construction conditions and/or natural and stable contours (elevations, profile, and gradient) following completion of work.	NMFS (National Marine Fisheries Service)
494	All structures necessary for in-water work will be removed immediately following completion of in-water work.	NMFS (National Marine Fisheries Service)