Appendix G.

Patuxent Research Refuge Impoundment Structured Decision-making Summary Report

March 30, 2012

Table of Contents

1. Introduction G-2

2. Comprehensive Conservation Plan Objectives G-3

3. Objectives for the Wetland Decision Analysis G-6

4. Measuring Objectives G-9

5. Evaluation Measures for the Objectives G-11

6. Value Functions for Objectives G-14

7. Management Alternatives G-16

8. Costs G-17

9. Putting it all Together – The Analysis G-17

10. Use of SDM results in the CCP G-25

Appendix 1 – Workshop Participants G-25

Abstract

Summary report of structured decision-making meetings held at Patuxent Research Refuge November 2010 to May 2011. The refuge staff and invited experts reviewed and discussed the future management of the refuge's artificial wetlands.

1. Introduction

While developing the Comprehensive Conservation Plan (CCP), the staff at Patuxent Research Refuge (refuge) developed a process to determine the best management option for refuge impoundments that will achieve refuge objectives. Patuxent Research Refuge manages both natural and artificial wetlands, with and without water control structures (WCS). The scope of the decision for this Structured Decision-making (SDM) workshop was discussed and the group determined to focus on artificial wetlands with and without water control structures. A decision timeframe of 15 years was set, to coincide with the timeframe of the refuge's CCP.

The workshop participants determined the problem statement to be:

What is the best management strategy to achieve the highest resource contribution for each artificial wetland?

To provide workshop participants with a first-hand view of the different types of artificial wetlands and some of the problems the refuge staff is facing, a few of the impoundments were visited. The group looked at impoundments with water control structures, wetlands with artificial barriers, impoundments designed for research, and constructed wetlands.

The purpose of this report is to explain and document the steps taken for this decision process and to provide an outline which could be applied at other refuges to support resource allocation decisions. SDM is a strategic approach to decision-making involving the following five steps:

1. Specify wetland objectives and scales for measuring achievement.
2. Develop management action alternatives that could achieve the objectives.
3. Determine how well all of the management action alternatives achieve the wetland objectives for each impoundment.
4. Consider tradeoffs among the alternatives.
5. Select the alternative that best achieves the wetland objectives for each impoundment, taking into account constraints.

2. Comprehensive Conservation Plan Objectives

The impoundments of Patuxent Research Refuge have been established since its origin. Several impoundments were created through gravel pits, while many were created for waterfowl research and mitigation efforts. During the workshop, the current biological objectives were reviewed along with other objectives to assist with determining future management options. The biological objectives may change or be altered due to the discussions and outcomes of the meetings and analysis. Below are the draft CCP goals and objectives related to impoundment management at the time of the meeting:

Goal 1: Maintain and actively promote Patuxent Research Refuge as an "outdoor laboratory," providing a diversity of wildlife and natural resource research opportunities on the refuge in such areas as landscape conservation, habitat fragmentation, climate change, and other emerging issues, as well as the more traditional types of wildlife research, including inventory and monitoring techniques, land management, and understanding ecological processes. Research that supports the overall Service mission, and evaluates the best methods for protecting natural resources throughout the National Wildlife Refuge System and other land management agencies will be a priority.

Objective 1.1 Inventory and Monitoring
Maintain and restore native floodplain forest communities along the Patuxent and Little Patuxent Rivers with less than 10 percent invasive species to provide mature bottomland floodplain forests dominated by American beech, sweetgum, tuliptree, sycamore, red maple, and pin oak to provide breeding, nesting and migratory stopover habitat for migratory bird species of conservation concern; including Acadian flycatcher, cerulean warbler, Kentucky warbler, Louisiana waterthrush, and prothonotary warbler and also to benefit eastern red bat and eastern box turtle. Provide diverse upland forest habitat with:

- Dense underbrush along streams and nesting snags (range average height of 3 to 6 feet and a dbh of at least 6 inches) for prothonotary warbler;
- Closed forest canopy (greater than 80 percent), sparse herbaceous canopy cover (less than 25 percent) and sparse to moderate shrub canopy cover (75 percent) for Louisiana waterthrush;
- A slightly open canopy, dense understory, and well-developed ground cover for Kentucky warbler;
- Canopies 5 to 20 feet above the ground; and
- Open underneath for summer roosting of eastern red bats.

Objective 1.2 Research and Scientific Assessments (Local, National, and International)
Maintain and restore native upland forest communities with less than 10 percent invasive species overall to provide mature upland forests dominated by American beech, northern red oak, white oak, tuliptree, southern red oak, and black oak to provide breeding, nesting and migratory stopover habitat for Acadian flycatcher, cerulean warbler, eastern wood-pewee, Louisiana waterthrush, wood thrush, worm-eating warbler and also to benefit silver-haired bat and eastern spadefoot toad. Provide diverse upland forest habitat with:

- Closed canopy and dense understory for Acadian flycatchers;
- Forest canopy cover (greater than 85 to 90 percent, not less than 65 percent), large trees (greater than 12 inches dbh), and subcanopy cover (65 to 70 percent, not less than 45 percent) for cerulean warblers;
- Incomplete or sparse canopy layer with understories to 15 to 20.5 feet height, providing the broken canopy layer is sufficiently high above the understory for eastern wood-pewee;
- Minimum snag densities of eight per acre for silver-haired bat roosts; and
- Vernal pools for breeding and foraging habitat for eastern spadefoot.

Goal 2: Protect, maintain, and restore, where possible, the biological integrity, diversity, and environmental health of forested ecological communities to provide habitat for species of conservation concern, including migratory birds, mammals, amphibians, reptiles, and invertebrates.

Objective 2.1 Floodplain Forest and Swamp, to also include Depressional Forests and Shrub Wetlands

Maintain, protect, and restore the aquatic habitat of the Patuxent, Little Patuxent, and Anacostia River watersheds within the refuge, to provide spawning, nursery, foraging, and cover habitat for aquatic resources of conservation concern; including American brook lamprey, American eel, American and hickory shad, blueback herring, comely shiner, glassy darter, stripeback darter and also to benefit other species of conservation concern, such as eastern box turtle, and triangle floater. Provide a variety of substrates including:

- Pea gravel for spawning American brook lamprey;
- Fine sand and muck for American brook lamprey larvae;
- Stony riffles for spawning stripeback darter;
- Gravel, sand, and detritus for spawning alewife; and
- Streams with a pH greater than 6.4, turbidity less than 15 NTU, and depths less than 20 inches for glassy darter.

Objective 2.2 Upland Deciduous, Pine, and Mixed Forest and Associated Wetlands

Maintain and restore the upland forest communities to provide mature upland forests dominated by American beech, northern red oak, white oak, tuliptree, southern red oak, and black oak to provide breeding, nesting and migratory stopover habitat for migratory bird species of conservation concern including; Acadian flycatcher, cerulean warbler, eastern wood-pewee, Kentucky warbler, Louisiana waterthrush, prothonatary warbler, wood thrush, worm-eating warbler and also to benefit eastern red bat and eastern spadefoot toad.

Goal 3: Protect, maintain, and restore, where possible, the biological integrity, diversity, and environmental health of refuge aquatic habitats, including the Patuxent, Little Patuxent, and Anacostia River watersheds, and impoundments, to provide habitat for migratory bird species of conservation concern; including American black duck, solitary sandpiper, green heron, greater and lesser yellowlegs

and also to benefit other species of conservation concern, such as eastern spadefoot, and elfin skimmer. Restore impoundments where greater conservation values result from restoration to natural hydrology.

- Provide a mix of shallow water (less than 6 inches water depth) and mudflats, by allowing exposed mudflats to increase to maximum exposure to provide for foraging habitat from mid-April to mid-May to support migrating shorebirds and wading birds.
- Maintain approximately 50 percent open water and floating vegetation coverage, initiating draw down by June 21 when floating vegetation coverage of pond lily, water shield, and spatter dock exceeds 50 percent and reflooding to 6 to 12 inches immediately after first frost or by the end of October.
- Provide seeds and roots of red-rooted sedge, barnyard grass, and smartweed for waterfowl during peak migration in mid-November by reflooding to 6 to 12 inches of water depth immediately after first frost or by the end of October.
- Provide restored forested wetland communities with a mostly closed to semi-open canopy along the reaches of gently sloping streams with a vegetation mosaic of small shrubs and trees including blackgum, swamp azalea, sweetbay magnolia, highbush blueberry, and dangleberry with open, sedge and graminoid dominated patches.

Objective 3.1 Coastal Plain River and Coastal Plain Stream Habitats
Manage the 5.5-mile Baltimore Gas and Electric and 3.5-mile Pepco powerline right-of-ways to provide scrub-shrub breeding, nesting and migratory stopover habitat for migratory bird species of conservation concern; including American woodcock, brown thrasher, field sparrow, prairie warbler, and white-eyed vireo and also to benefit eastern spadefoot and Indian skipper.

- Provide berry-producing trees, shrubs and vines, such as dogwood, ciborium, hawthorn, crabapple, blueberry, raspberry, sumac, and grape for food, interspersed with small open areas for foraging brown thrashers.
- Provide low shrubs and small trees for nesting birds, including brown thrashers (to 12 feet), prairie warbler (1 to 10 feet), and white-eyed vireo (1 to 8 feet).
- Provide areas of low to moderate shrub density with 50 to 75 percent of shrubs less than 5 feet, and shrub cover between 15 to 35 percent for field sparrows.
- Provide young tree and shrubs species alder, hawthorns, dogwood, spicebush, and viburnum on moist soils for feeding, daytime cover, and nesting for American woodcock.

Objective 3.2 Impoundments of Open Water, Emergent, Shrub, and Forest
Manage grasslands in large blocks (greater than 25 acres), dominated by native species with a mix of cool and warm season grasses, less than 20 percent forbs and less than 3 percent shrub cover, to provide resting and foraging habitat for migrating and wintering bird species of conservation concern; including eastern meadowlark, eastern kingbird, field sparrow, and grasshopper sparrow and to benefit pollinating insects. Allow the remaining fields (less than 25 acres) to revert to forest habitat, unless mowing is required for administrative purposes, environmental education, public use, or public viewing.

- Provide short- to medium-height bunch grasses interspersed with patches of bare ground, shallow litter layer, scattered forbs, and few shrubs for foraging grasshopper sparrows.
- Provide open habitat adjacent to nearby perches for foraging passerine birds, including the eastern kingbird.
- Provide a mix of flowering plant species for pollinating insects.

Objective 3.3 Emergent Wetlands (Freshwater, Nontidal)
Manage the 32 constructed impoundments with water control structures to provide managed habitat for migratory bird species of conservation concern; including American black duck, solitary sandpiper, greater and lesser yellowlegs and also to benefit for other species of conservation concern, such as eastern spadefoot and elfin skimmer.

Goal 4: Manage refuge non-forested upland communities to provide ecological structure, composition, and function to support native plants and wildlife, including species of conservation concern. Where appropriate, restore the biological integrity and diversity of these habitats.

Objective 4.1 Shrub/Early Succession Forest Habitat
Manage the 5.5-mile Baltimore Gas and Electric and 3.5-mile Pepco powerline right-of-ways to provide scrub-shrub habitat to provide breeding, nesting and migratory stopover habitat for migratory bird species of conservation concern; including brown thrasher, field sparrow, prairie warbler, and white-eyed vireo and also to benefit eastern spadefoot and Indian skipper.

Objective 4.2 Grasslands/Old Fields
Maintain grassland in large (greater than 25 acres) parcels and in close proximity, dominated by native species with a mix of cool and warm season grasses, less than 20 percent forbs and less than 3 percent shrub cover, to provide nesting and foraging habitat to benefit migratory bird species of conservation concern; including American woodcock, eastern kingbird, and grasshopper sparrow and also to benefit pollinating insects.

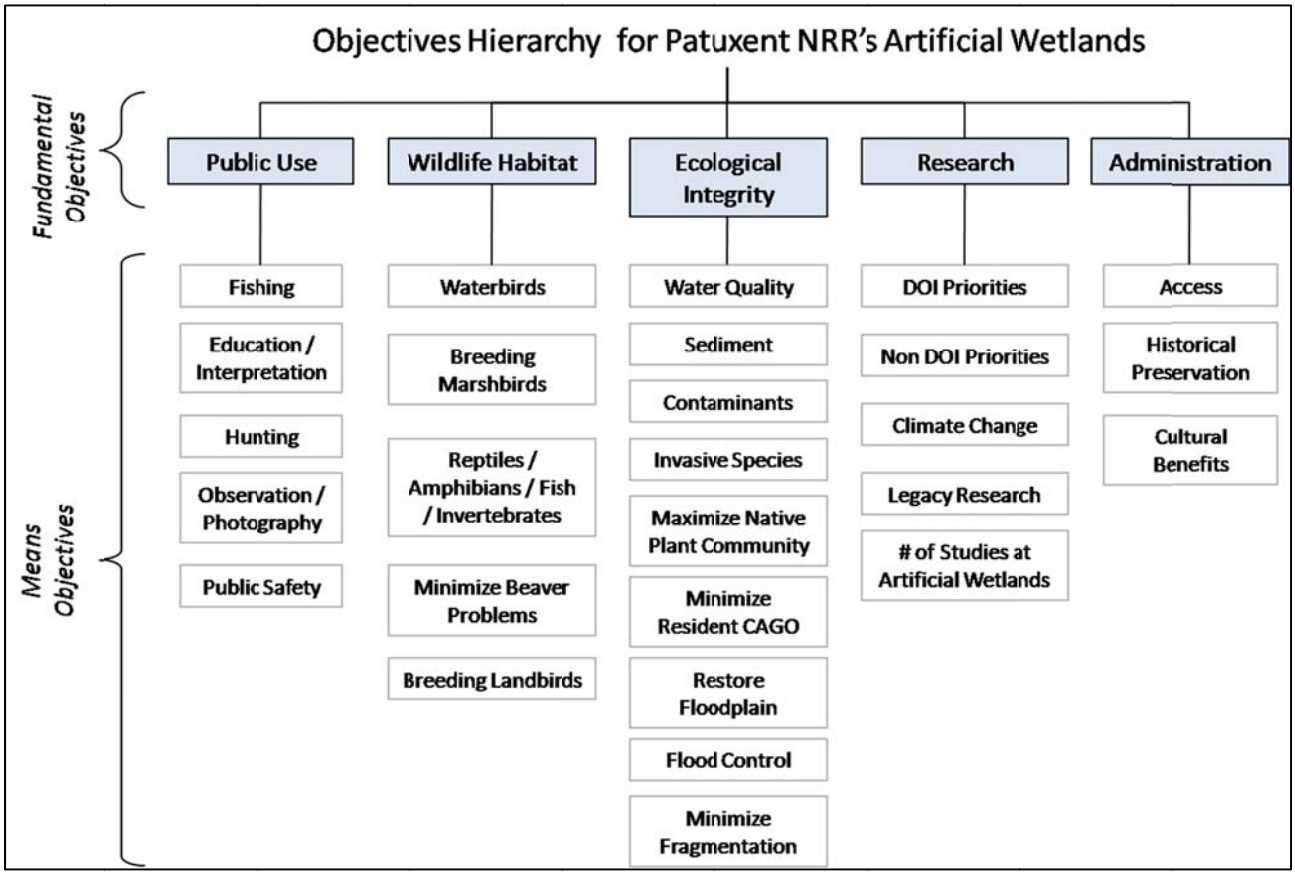
3. Objectives for the Wetland Decision Analysis

For the purposes of the SDM workshop, participants discussed the management objectives they wanted to achieve through management of artificial wetlands to meet the CCP goals and objectives. Below is the initial list of objectives (potential metrics for some in parentheses), which were then used to develop an objectives hierarchy (figure G-1) for artificial wetlands.

1. Fishing opportunities (conduct angler surveys, determine # of repeat anglers)
2. Education - demonstrate research and management techniques, show examples of how wetlands are managed (determine success, interaction with visitors, number of visitors, visitor feedback)
3. Waterfowl hunting opportunity (number fishing permits issued, review hunter reports)

4. Research opportunity - conduct research that meets the U.S. Department of the Interior priority topics, i.e., effects of management, invasives, non-target species, etc. (number of projects)
5. Waterbird habitat (waterfowl, shorebirds, waders, and raptor surveys)
6. Amphibian/reptile/fish/invertebrate habitat
7. Wildlife observation and photography
8. Water quality, sediment control - minimize contaminant issues as related to the biological integrity and diversity and environmental health policy (BIDEH)
9. Climate change concerns, connectivity
10. Historical preservation
11. Minimize forest fragmentation (BIDEH)
12. Minimize resident Canada goose population (BIDEH)
13. Minimize beaver problems
14. Flood control
15. Maintain/maximize native wetland plant communities. (BIDEH)
16. Human access
17. Management costs/efficiency
18. Breeding habitat for marshbirds
19. Restoration of bottomland floodplain forest. (BIDEH)
20. Restore natural hydrology (BIDEH)
21. Mitigation

Figure G-1. Initial Objectives Hierarchy



Subsequent to identifying the initial list of 21 wetland objectives, each individual objective was critically evaluated as to whether it was a:

1. Critical Objective – Actions related to this objective are sufficiently important that management of impoundments may be altered in order to achieve the objective.

2. Correlated Objective – Actions related to this objective may also achieve another objective. Combine these objectives into one.

3. Null Objective – Actions related to this objective are of equal value to all the alternatives. If the objective was equal at all wetlands, then it did not need to be considered within the decision process.

4. Constraint - Is the objective actually a constraint? If the action has equal impact to the management of all wetlands and limits the alternatives, it is a constraint and is not used in this aspect of the decision process.

Extensive discussion occurred for each of the means objectives. As a result, the initial list of 21 objectives was reduced to 6 final objectives that influence refuge wetland management decisions. The following objectives fell into the above categories, and were therefore removed from the wetland decision-making process. The bullets below provide a summary of the discussion which led to dropping them from the final objectives hierarchy.

- Minimize Beaver Problems, Minimize Resident Canada Goose and Invasive Species – These were found to be impediments that require strategies to correct, rather than objectives of wetland management.

- Water Quality, Sediment, and Contaminants - Water quality is very important in meeting refuge objectives, as well as, larger landscape environmental quality concerns. While the refuge's impoundments seem small in size, if converted to forest, their filtering and buffering effect may serve a significant role due to their location. While the wetlands may have a benefit to landscape water quality, that of a riparian or forested habitat may have an even greater benefit to water quality. It is not likely that water quality at the larger landscape would be impaired if some of the refuges wetlands were eliminated. The potential for contaminants within bottom sediment would be examined to ensure that they would not be flushed into the river system.

Additionally, three of the initially identified fundamental objectives (public use, research and administration) were determined to not directly enter into the decisions regarding the management of refuge wetlands for biological resources.

- Public Use and Research are not drivers of wetland management decisions, but rather are dependent upon achieving wetland resource objectives. For example, targeted research is conducted to understand uncertain outcomes of management

decisions. Appropriate Public Use is a secondary decision and is determined after wetland management decisions are made.

- Administrative concerns were discussed and identified as important constraints that need to be considered for each wetland, after initial resource management decisions have been made.

4. Measuring Objectives

Five final means objectives were selected to continue with the decision process. Below, each objective has a short justification for including it along with the metrics that were identified to evaluate each wetland with.

1. **Breeding Forest Landbirds**
   A large portion of the refuge is comprised of floodplain forest that benefits a variety of breeding forest landbirds. Through the refuge's habitat management planning process it was determined that the refuge can make a significant contribution to this group of birds. It was also identified that many of the refuge's artificial wetlands are contributing to forest fragmentation that adversely impacts this group of birds.

   a. Level of fragmentation

2. **Waterbirds**
   During recent years wetland management practices have been undertaken to study habitat for waterbird groups such as shorebirds and wading birds. Due to the large number and variety of artificial wetlands found at the refuge, it is felt that some of these wetlands can provide valuable habitat to wetland dependent wildlife.

   a. Number of individuals using wetlands
   b. Species richness using wetlands (amphibians, reptiles, etc.)

3. **Fish Populations**
   Fish populations on the refuge provide opportunities for public fishing and food for other animals including wading birds. Healthy fish populations contribute to the natural systems on the refuge. Not all of the impoundments support fish populations.

   a. Wetland size
   b. Depth
   c. Hydrology
   d. Connectivity

4. **Odonata**
   Patuxent Research Refuge has been identified as being very important for a large number of odonata (dragonflies and damselflies). Richard Orr, a local

entomologist, has been monitoring odonata at the refuge for a number of years. Presently 105 species have been identified to use refuge wetlands, with many of these being very rare S1 or S2 species, some of which are found nowhere else within the State of Maryland. Odonata were added to the objectives hierarchy.

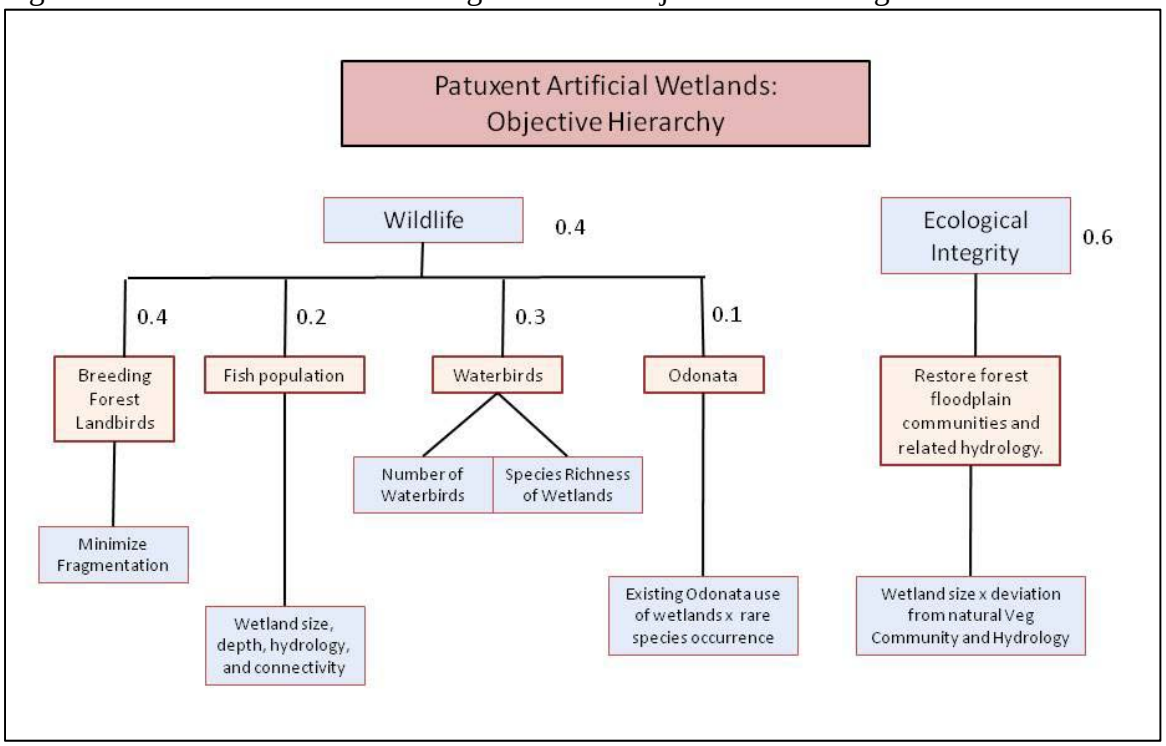
a. Existing odonata use of wetlands
b. Rare species occurrences

5. **Ecological Integrity**
The refuge identified restoration of ecological integrity as an important objective that allows the refuge to achieve its natural intrinsic value to wildlife resources. The objective is to improve the refuge's contribution toward landscape ecological integrity. Ecological integrity was defined as allowing natural processes that shape ecosystems to occur, along with provision of the biological communities that would historically be found within a site.

a. Wetland size
b. Deviation from natural vegetation community
c. Hydrology

Each objective was weighted to determine relative importance (figure G-2.) Objective weights are critical to the analysis process when determining various management alternatives for each wetland, and which objective should be prioritized, given that all objectives cannot be met within any given wetland.

Figure G-2. Patuxent Research Refuge Wetland Objectives and Weights



5. Evaluation Measures for the Objectives

For each of the objectives there needs to be a way to measure and determine success in meeting that objective. Each of the five final objectives was evaluated and metrics identified to determine how well each artificial wetland may contribute toward the respective objective. Workshop participants developed evaluation measures for each objective.

1. **Breeding Forest Landbirds**
   To determine the extent each wetland contributes toward forest fragmentation, the GIS program Fragstats was used. Each wetland was compared to surrounding vegetation communities, and an overall score was determined as to the wetlands contribution to refugewide fragmentation.

   Fragstats was developed to describe landscape level characteristics. For this exercise, we examined the level of fragmentation caused by the impoundments. It assigned a numerical value to the fragmentation from each impoundment, based upon characteristics such as size and adjacent habitat.

2. **Waterbirds**
   Existing contribution of each refuge artificial wetland was evaluated using refuge waterbird survey data. Wetlands were scored on numbers of waterbirds using each wetland, as well as, number of individual species that annually use each wetland.

   a. Numbers of Waterbirds: Refuge staff surveyed waterbird use of wetlands from 1996 to 2009. For each year, the maximum number of waterbirds counted during any single survey was determined. This maximum number for each year was averaged across all years. The average number of maximum bird use per wetland was identified as the contribution of each individual wetland towards waterbird use.

      To project waterbird use given different management scenarios within each wetland, the same data were analyzed for wetlands where the following management regimes were undertaken during different years; water level drawdowns, static annual water regime, and green-tree reservoir management. For those wetlands where no data were available, we projected waterbird use given possible management regimes and wetland acreage.

   b. Wetland waterbird species richness: It was identified that wetlands with greater numbers of species using the wetland provide more varied habitat and a greater contribution toward the waterbird community. Waterbird species richness was calculated as the maximum number of individual species that used each wetland during a year. Maximum number of species using a wetland was then averaged across years from 1996 to 2009. Projections of waterbird species richness under different management

alternatives were made similar to the above maximum number of waterbird use of a wetland.

3. Fish Populations

The refuge had little information or data on fish populations using the various wetlands. As a result, we projected fish population values of each wetland using the following formula:

Fish Pop Value = ((S + D + C) * H))

S= Wetland Size
- 1= <2acres
- 2= 2-10acres
- 3= >10 acres

D= Wetland Depth
- 1= <5ft
- 2=>5ft

C=Connectivity
- 1=isolated wetland
- 2=wetland connected to other wetlands, water bodies via stream.

H= Hydrology
- 0= temporary wetland, dries-up during summer
- 1= dries up only during severe drought
- 2= can maintain static water level throughout year

Wetlands that are periodically subjected to drought and isolated from other wetlands were automatically given a fish population score of 0. Whereas wetlands that periodically are subjected to drought, but are connected to other wetlands were scored using the above formula.

4. Odonata

To rank refuge wetland value to odonata, Richard Orr tabulated his historical data and provided each wetland a score from low to high as to odonata diversity with the wetland. He also identified lists of rare S1 or S2 species if they occurred within a wetland. Thus, the following was used to develop an odonata value for each wetland:

Each wetland was given a score of low, medium, high, as to its value to odonata diversity.
- Low = 1
- Med = 2
- High= 3

If S1 or S2 odonata were found within a wetland, the score was multiplied by the number of S1/S2 species found within the wetland.

Odonata life cycles generally require permanent water regimes, whereas refuge wetlands are periodically managed with a dynamic water regime of conducting drawdowns. During these drawdowns the majority of water is drained, however small pools will remain within the wetland. Thus, odonata value of a wetland under dynamic water regime was projected to be 75 percent of its static water regime value. Wetlands which may be restored to a natural floodplain hydrology were projected to have no value for odonata.

5. Ecological Integrity

The refuge identified restoration of ecological integrity as an important objective that allows the refuge to achieve its natural intrinsic value to wildlife resources. Ecological integrity was defined as allowing natural processes that shape ecosystems to occur, along with provision of the biological communities that should normally be found within a site.

The objective is to improve the refuge's contribution toward landscape ecological integrity. To achieve greater ecological integrity of the refuge landscape each artificial wetland was evaluated as to its deviation from a natural hydrological regime and vegetation communities that are not a part of the North Atlantic Coastal Plain Stream and River Ecological System (CES 203.070).

Formula to calculate a wetland's contribution toward ecological integrity under different management scenarios:

Integrity Score = Wetland size category x Integrity value

Size Categories:

1 = 1-2 acres
2 = 2-10 acres
3 = 10-20 acres
4 = >20 acres

Integrity values:

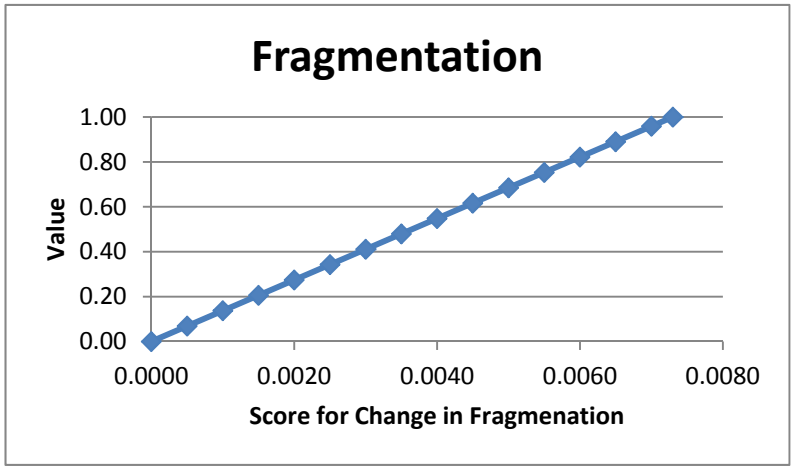
Value	Integrity Value Description
0	Wetland managed with static water regime and altered vegetation community that is not associated with the ecological system.
1	Wetland managed with modified hydrology (dynamic water levels within impoundments) and altered vegetation community that is not associated with the ecological system.
2	Wetland managed with modified hydrology and vegetation community that is part of the ecological system.
3	Wetland restored to natural occurring hydrology and vegetation community that is part of the ecological system.

6. Value Functions for Objectives

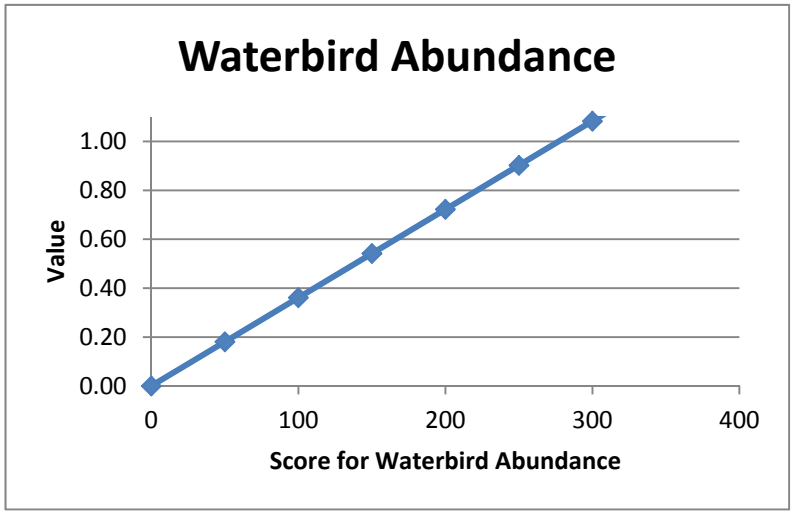
For this decision, we have five objectives we are trying to achieve for each wetland. This is therefore called a multiobjective analysis. To conduct a multiobjective analysis, is it necessary to determine a value function, which combines the evaluation measures of the five objectives into a single measure of the overall value of each of the alternatives for a wetland.

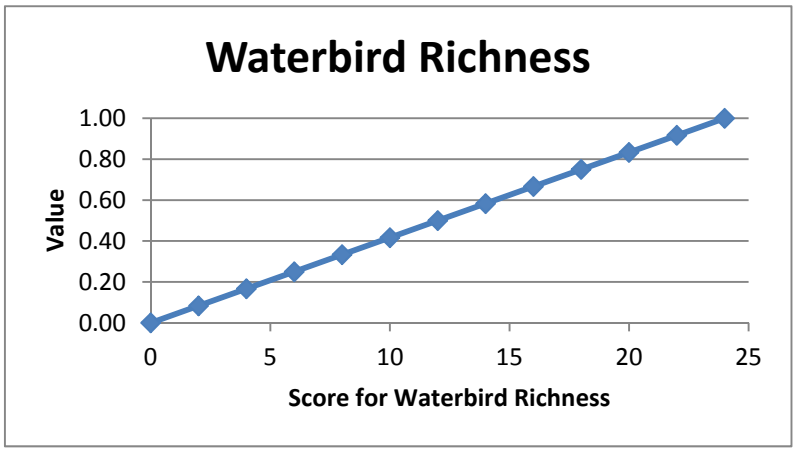
Each objective has a unique evaluation measure, a unique score. For instance, integrity is a combination of wetland size (1 to 4) and an integrity value (1 to 3), while waterbird use is the averaged maximum number of waterbirds surveyed over a 14-year period (0 to 350). The objective scores need to be transformed into a common scale that can equally represent how 'good' or 'poor' an alternative is in relation to another alternative. To do this, a value function is determined for each objective. Value functions are a scale of 0 to 1, where 0 is the least-preferred objective score and 1 is the most-preferred objective score.

1. **Breeding Forest Landbirds**

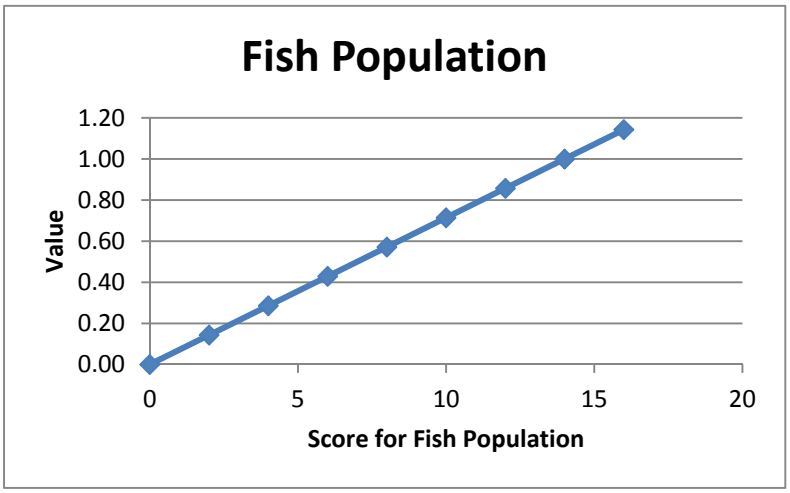


2. **Waterbirds**

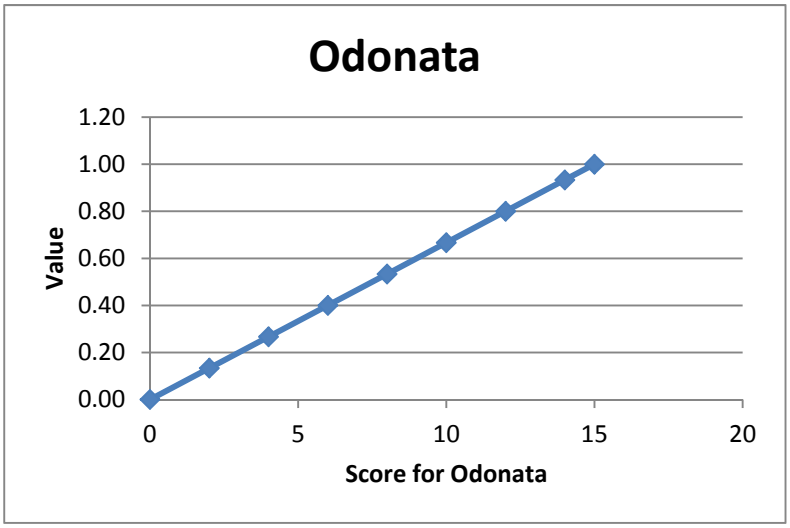




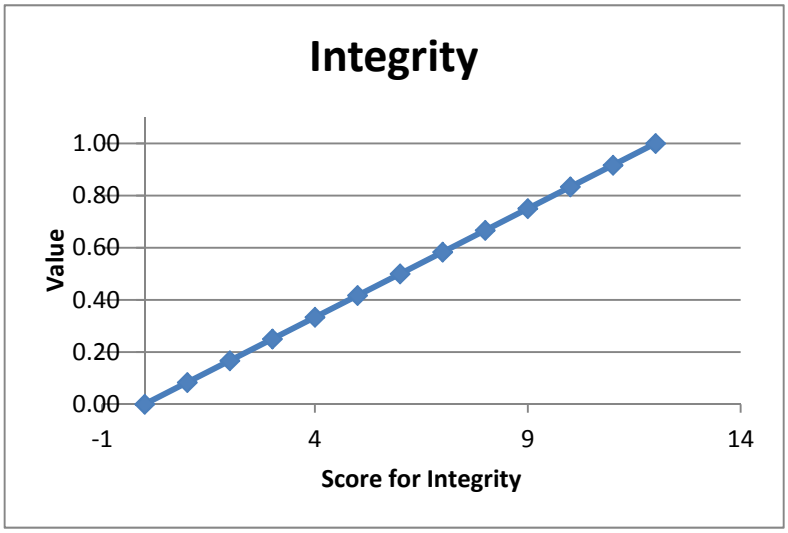
3. Fish



4. Odonata



5. **Ecological Integrity**



7. Management Alternatives

The structured decision-making workshop was oriented toward developing a decision process that will allow the refuge to determine the best management options for each artificial wetland. Workshop participants discussed possible alternative management actions relative to current management and developed the following list:

1. **Restore wetland back to natural habitat.**
   This could include any of the following:
   a. Remove water control structure
   b. Remove dike
   c. Install culverts or water control structure
   d. Restore natural hydrology
   e. Revegetate with native plants
   f. Control invasives
   g. Fill wetland and restore back to natural topography

2. **Manage wetland as a "wetland."**
   Wetlands are sometimes dry and sometimes wet. This alternative will provide shallow wetlands conducive to waterbirds, amphibians, etc.
   1. Dynamic water levels
   2. Control invasives
   3. Combine impoundments to create larger unit

3. **Manage for static water levels.**
   This meets the fishing and other public use objectives.

4. **Convert to green-tree reservoir.**
   This is a hybrid between alternative 1 and 2. It will move the refuge toward BIDEH by restoring forested wetlands. But also provide for the needs of waterfowl and amphibians, by being able to manipulate hydrology during the annual cycle.

5. **No active management.**

The above management alternatives were used in the consequence table in the "Management Actions" column. They are used to list the different potential management scenarios for a particular artificial wetland. For each individual wetland, feasible alternative management strategies were discussed. Refuge staff only identified alternative management scenarios that could feasibly be accomplished within any particular wetland. In some instances, constraints on what was feasible within a wetland resulted in a "no management option" and thus the wetland was eliminated from the decision process. In other situations, only one or two management alternatives were feasible, while some wetlands had a wide variety of alternatives.

The cost of implementing each management alternative within a wetland was also determined.

8. Costs

Along with determining the management option with the highest management benefit for Patuxent Research Refuge impoundments, it was necessary to balance this against the costs in order to determine the optimum option (portfolio) that was also fiscally achievable. With this in mind, a relatively generic, high level cost estimate was developed for each management alternative by attributing actions to each alternative and assigning applicable unit costs per action.

9. Putting it all Together – The Analysis

Overview

A multi-objective decision analysis was conducted for 33 artificial wetlands to select a portfolio of management actions which result in the highest management benefit given funding constraints. To do this, the anticipated response from management actions for each of the wetlands was scored based on five objectives. The scores were combined into one overall management benefit rating by converting objective scores into value functions and applying objective weights. Using the management benefit rating along with start up and annual costs, a portfolio of management actions was generated by the Excel analysis tool solver. One management action alternative was selected for each wetland resulting in a portfolio where the combined management actions provide the highest management benefit for the refuge.

The Steps

1. **Determine Wetlands for the Decision Analysis**
   There are 59 wetland units on Patuxent Research Refuge. Not all of the wetlands were suited for this decision process due to lack of control, no reasonable management alternatives, etc. Thirty-three wetlands were selected for the decision analysis.

PONDS OF PATUXENT RESEARCH REFUGE Removed from SDM JANUARY 2011					COMMENTS
Note: **Y** = Man made with some water level control					
X = Natural/beaver affected or man made gravel pit with no water control structuers					
Y	North Tract	Blue Heron Pond	9.46		Mitigation pond
X	North Tract	Dragonfly Pond		0.85	Old clay pit; no mgmt. capabilities
Y	North Tract	Lake Allen	22.77		Fishing area
Y	North Tract	Merganser Pond	2.01		Mitigation pond
X	North Tract	Midway Branch Marsh		1.72	Fish ladder on east side of rd; no WCS but i
Y	North Tract	New Marsh		10.51	Fishing area; old ox bow; no working WCS
Y	North Tract	Bailey Bridge ~~Pond~~ Marsh	1.90		Maybe replace culvert to working condition
X	North Tract	Bullfrog Pond		5.29	Possibly a gravel pit; leaving on list b/c may
Y	North Tract	Cattail ~~Marsh~~ Pond	2.38		Used for fishing; formerly used for dog trainin
X	North Tract	Gravel Pit Pond		0.43	Just as the name says....
X	North Tract	Kingfisher Pond		4.41	Same as Bullfrog Pond
X	North Tract	New Swamp		5.62	Nothing can be done with this area
X	North Tract	Powerline Swamp		3.90	Culvert but no WCS; Impounded by rd; goe

2. **Determine Wetland Management Objectives**
   As discussed in section 3, the five wetland objectives are: breeding forest landbirds, waterbird use and richness, fish, odonata, and ecological integrity.

3. **Determine What to Measure for the Objectives**
   As discussed in section 4:

Objective	Measurement
Breeding Forest Landbirds	Level of Fragmentation
Waterbird Use	# of Individuals
Waterbird Richness	Species Richness
Fish	Wetland Size, Depth, Hydrology, Connectivity
Odonata	# of Species, Rare Species Occurrences
Ecological Integrity	Wetland Size, Deviation from Natural Communities, Hydrology

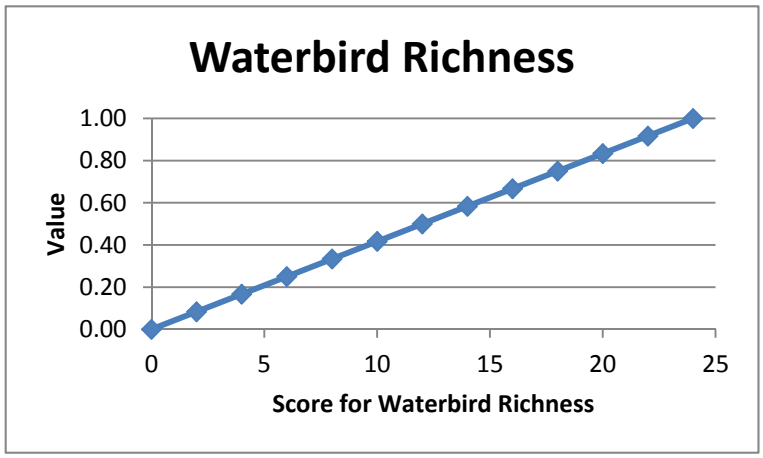
4. **Develop Evaluation Measures for the Objectives**
   As discussed in section 5:

Objective	Measurement	Evaluation Measure
Breeding Forest Landbirds	Level of fragmentation	FRAGSTAT results
Waterbird Use	# of individuals	Avg. # of birds (1996-2009)
Waterbird Richness	Species richness	Avg. max.. waterbird species (1996-2009)
Fish	Fish pop. value = *((S + D + C) * H))*	
	Wetland size (S)	1=<2acres; 2 = 2to10a; 3 = >10a

Objective	Measurement	Evaluation Measure
	Depth (D)	1 = < 5 ft.; 2 = > 5 ft.
	Connectivity (C)	1 = isolated; 1 = connected
	Hydrology (H)	0 = temporary; 1 = dries in drought; 3 = maintains static water level
Odonata	Odonata score = *species category* X *# of S1/S2*	
	# of species (categories)	low = 1; med = 2; high = 3
	Rare species occurrences	# of S1/S2 species that occur in the wetland
Ecological Integrity	Integrity score = *wetland size* X *integrity value*	
	Wetland size	1 = 1-2acres; 2 = 2-10a; 3 = 10-20a; 4 = > 20a
	Deviation from natural communities	Integrity value = 0–3 based on the descriptions with a range of ecological system and hydrologic conditions
	Hydrology	Used to determine integrity value

5. Develop Value Functions for the Objectives

As discussed in section 6, the value function for waterbird richness:



6. Develop Management Alternatives

Alternatives	Techniques
Restore wetland back to natural habitat	Remove water control structure
	Remove dike
	Install culverts or water control structure
	Restore natural topography
	Revegetate with native plants
	Control invasives
	Fill wetland and restore back to natural topography

Alternatives	Techniques
Manage wetland as a “wetland”	Dynamic water levels
	Control invasives
	Combine impoundments to create larger unit
Manage for static water levels	Maintain water control structure
	Keep water levels constant throughout the year
Convert to green-tree reservoir	Maintain water control structure
	Revegetate with water tolerant tree species
	Dynamic water levels
No active management	No water control structure in place
	Water levels dependent upon natural precipitation

Each wetland was reviewed and given two or more management alternatives:

Wetland	Mgmt Action
Millrace Pond	1.Manage wetland as a "wetland" (static water) tree removal, clean culverts, beaver mgmt.
Millrace Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culverts
Millrace Pond	3.Manage wetland as "wetland" (repair road to function as a dike & remove culverts, install agr
Millrace Pond	4.Convert to green-tree reservoir. (repair road to function as dike, install agridrain to manage
Millrace Pond	5.Convert to green-tree reservoir (repair road to function as dike, install agridrain to manage wa
Dragonfly Pond	1.No action.
Dragonfly Pond	2.Restore to natural topography, (fill gravel pit)
Salamander Pond	1.No action.
Salamander Pond	2.Restore to natural topography, (Fill)
Wood Duck Pond	1.Manage wetland as a "wetland" (static water) and do nothing,
Wood Duck Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culverts
Wood Duck Pond	3.Remove Center Dike & install 1 agridrain at NE corner
Bluegill Pond	1.Restore wetland back to natural hydrology. (remove wcs and dike)
Bluegill Pond	2.No active management
Bluegill Pond	3.Manage wetland as a "wetland" (dynamic water levels)

7. **Calculate Scores for the Alternatives**
Using the evaluation measures, scores were calculated for each of the management alternatives for a wetland. Calculating the scores was time consuming, not only due to the number of alternatives and complexity of some of the formulas, but also because estimates needed to be made for conditions that don’t currently exist. Whenever possible, data from known conditions was applied to estimate similar future conditions.

SCORES (APPLES AND ORANGES)

Wetland	Mgmt Action	Integrity	WB Abund	WB Rich	Odonata	Fish	Frag	FragDiff
Millrace Pond	1.Manage wetland as a "wetland" (static water) tree removal, clean culverts, beaver mgmt.	0	71	10	3	6	0.3146	0.0000
Millrace Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culverts	12	0	0	0	0	0.3073	0.0073
Millrace Pond	3.Manage wetland as "wetland" (repair road to function as a dike & remove culverts, install agric	4	64	11	2.25	6	0.3146	0.0000
Millrace Pond	4.Convert to green-tree reservoir. (repair road to function as dike, install agridrain to manage wa	8	165	7	0	0	0.3073	0.0073
Millrace Pond	5.Convert to green-tree reservoir (repair road to function as dike, install agridrain to manage wat	8	165	7	0	0	0.3073	0.0073
Dragonfly Pond	1.No action.	0	17	6	1.01	0	0.3146	0.0000
Dragonfly Pond	2.Restore to natural topography, (fill gravel pit)	3	0	0	0	0	0.3145	0.0001
Salamander Pond	1.No action.	0	3	3	1.01	0	0.3146	0.0000
Salamander Pond	2.Restore to natural topography, (Fill)	3	0	0	0	0	0.3143	0.0003
Wood Duck Pond	1.Manage wetland as a "wetland" (static water) and do nothing,	0	46	11	1	0	0.3146	0.0000
Wood Duck Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culverts	0	0	0	0	0	0.3129	0.0017
Wood Duck Pond	3.Remove Center Dike & install 1 agridrain at NE corner	0	0	0	0	0	0.3129	0.0017

8. Calculate Weighted Values for Alternatives

In this step, the objective scores are transformed into comparable scales by using the value functions. This is also where the objective weights are used. Ecological Integrity was given a weight of .6 and Wildlife .4 (weights needs to sum to 1.0). There are five wildlife objectives, and each of these are given a weight based on the overall Wildlife weight of .4 and the weights that were assigned to them in the objectives hierarchy. The table below shows the breakdown of the weights, the bottom row shows the weights that were used in the calculations.

Wildlife					**Ecological Integrity**	
.4					.6	= 1
Waterbird Abundance	Waterbird Richness	Odonata	Fish	Fragmentation		
.3		.1	.2	.4		= 1
.06	.06	.04	.08	.16	.6	= 1

Using the calculation features of Excel, a formula is developed to apply the value functions and weights resulting in the table below. Note that the objectives are now on a scale of 0 to 1.

9. Calculate Management Benefit

WEIGHTED VALUES (ALL APPLES)

Wetland	Mgmt Action	Integrity	WB Abund	WB Rich	Odonata	Fish	FragDiff
Millrace Pond	1.Manage wetland as a "wetland" (static water) tree removal, clean culverts, bea	0.000	0.015	0.025	0.008	0.034	0.000
Millrace Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culver	0.600	0.000	0.000	0.000	0.000	0.160
Millrace Pond	3.Manage wetland as "wetland" (repair road to function as a dike & remove culve	0.200	0.014	0.028	0.006	0.034	0.000
Millrace Pond	4.Convert to green-tree reservoir. (repair road to function as dike, install agridrai	0.400	0.036	0.018	0.000	0.000	0.160
Millrace Pond	5.Convert to green-tree reservoir (repair road to function as dike, install agridrair	0.400	0.036	0.018	0.000	0.000	0.160
Dragonfly Pond	1.No action.	0.000	0.004	0.015	0.003	0.000	0.000
Dragonfly Pond	2.Restore to natural topography, (fill gravel pit)	0.150	0.000	0.000	0.000	0.000	0.002
Salamander Pond	1.No action.	0.000	0.001	0.008	0.003	0.000	0.000
Salamander Pond	2.Restore to natural topography, (Fill)	0.150	0.000	0.000	0.000	0.000	0.007
Wood Duck Pond	1.Manage wetland as a "wetland" (static water) and do nothing,	0.000	0.010	0.028	0.003	0.000	0.000
Wood Duck Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culvert	0.000	0.000	0.000	0.000	0.000	0.037
Wood Duck Pond	3.Remove Center Dike & install 1 agridrain at NE corner	0.000	0.000	0.000	0.000	0.000	0.037
Bluegill Pond	1.Restore wetland back to natural hydrology. (remove wcs and dike)	0.150	0.000	0.000	0.000	0.000	0.007
Bluegill Pond	2.No active management	0.000	0.002	0.013	0.005	0.000	0.000
Bluegill Pond	3.Manage wetland as a "wetland" (dynamic water levels)	[illegible]	0.002	0.013	0.003	[illegible]	[illegible]

Each objective contribution for a management alternative is summed across rows to determine the management benefit of a selected wetland and management alternative.

WEIGHTED VALUES (ALL APPLES)								
Wetland	Mgmt Action	Integrity	WB Abund	WB Rich	Odonata	Fish	FragDiff	Management Benefit
Millrace Pond	1.Manage wetland as a "wetland" (static water) tree removal, clean culverts, bea	0.000	0.015	0.025	0.008	0.034	0.000	0.083
Millrace Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culver	0.600	0.000	0.000	0.000	0.000	0.160	0.760
Millrace Pond	3.Manage wetland as "wetland" (repair road to function as a dike & remove culv	0.200	0.014	0.028	0.006	0.034	0.000	0.282
Millrace Pond	4.Convert to green-tree reservoir. (repair road to function as dike, install agridrai	0.400	0.036	0.018	0.000	0.000	0.160	0.613
Millrace Pond	5.Convert to green-tree reservoir (repair road to function as dike, install agridrair	0.400	0.036	0.018	0.000	0.000	0.160	0.613
Dragonfly Pond	1.No action.	0.000	0.004	0.015	0.003	0.000	0.000	0.021
Dragonfly Pond	2.Restore to natural topography, (fill gravel pit)	0.150	0.000	0.000	0.000	0.000	0.002	0.152
Salamander Pond	1.No action.	0.000	0.001	0.008	0.003	0.000	0.000	0.011
Salamander Pond	2.Restore to natural topography, (Fill)	0.150	0.000	0.000	0.000	0.000	0.007	0.157
Wood Duck Pond	1.Manage wetland as a "wetland" (static water) and do nothing,	0.000	0.010	0.028	0.003	0.000	0.000	0.040
Wood Duck Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culvert	0.000	0.000	0.000	0.000	0.000	0.037	0.037
Wood Duck Pond	3.Remove Center Dike & install 1 agridrain at NE corner	0.000	0.000	0.000	0.000	0.000	0.037	0.037
Bluegill Pond	1.Restore wetland back to natural hydrology. (remove wcs and dike)	0.150	0.000	0.000	0.000	0.000	0.007	0.157
Bluegill Pond	2.No active management	0.000	0.002	0.013	0.005	0.000	0.000	0.019
Bluegill Pond	3.Manage wetland as a "wetland" (dynamic water levels)	[illegible]	[illegible]	[illegible]	0.003	[illegible]	[illegible]	[illegible]

10. Calculate Costs

Each management alternative for each impoundment was assigned a cost estimate based on the individual actions attributed to each alternative. An initial construction estimate as well as an annual maintenance estimate was determined for each alternative. The costing model assumes that any initial construction work is performed in the first year and the maintenance cost applies to all 15 years of the decision timeframe. Cost figures were based on industry standard published databases such as RS Means or the Maryland State Highway Administration quarterly reports. Quantities were determined using known data if available and if not available, take-offs from aerial photography was used.

Wetland	Acres	WCS	Mgmt Actions	Upfront Cost	Maintenance Cost, per year
Millrace Pond	50.83	N	1.Manage wetland as a "wetland" (Static Water) tree removal, clean culverts, beaver mgmt.	$ -	$ 2,565.00
	50.83	N	2.Restore wetland back to natural habitat. Remove Dike	$ 274,500.00	$ -
	50.83	N	3.Restore wetland back to natural habitat.	$ -	$ -
	50.83	N	4.Manage wetland as a "wetland" (dynamic water levels), install WCS, repair dike.	$ 5,000.00	$ 1,365.00
	50.83	N	5.Convert to green-tree reservoir (allow trees to establish)	$ 5,000.00	$ 1,365.00
	50.83	N	6.Convert to green-tree reservoir. (plant trees)	$ 467,807.15	$ 1,365.00
Dragonfly Pond	0.85	N	1.No action.	$ -	$ 500.00
	0.85	N	2.Restore to natural topography, (fill gravel pit)	$ 110,000.00	$ -
	0.85	N	3.Restore to natural topography & convert to green tree reservoir (plant trees)	$ 117,739.25	$ -
Bailey Bridge Marsh	1.90	Y	1.No action.	$ -	$ 500.00
			2.Restore to natural topography,		

11. Conduct Benefit/Cost Analysis

An optimization procedure is then used, with constraints of capital and annual maintenance costs, to select the optimum portfolio of management alternatives for all wetlands to maximize refuge contribution toward wetland objectives. The portfolio of management alternatives is the list of all wetlands, with the recommended management action for each. The management action alternative with a 1 in the "Portfolio" column is the selected alternative for that wetland.

Optimization

Wetland	Mgmt Action	Porfolio	Mgmt Benefit	Startup $	Annual $ (15 yr)
Millrace Pond	1.Manage wetland as a "wetland" (static water) tree removal, clean culverts, bea	0	0.083	$0	$56,500
Millrace Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culver	1	0.760	$42,000	$54,000
Millrace Pond	3.Manage wetland as "wetland" (repair road to function as a dike & remove culve	0	0.282	$15,000	$20,500
Millrace Pond	4.Convert to green-tree reservoir. (repair road to function as dike, install agridrai	0	0.613	$15,000	$20,500
Millrace Pond	5.Convert to green-tree reservoir (repair road to function as dike, install agridrair	0	0.613	$477,807	$20,500
Dragonfly Pond	1.No action.	0	0.021	$0	$0
Dragonfly Pond	2.Restore to natural topography, (fill gravel pit)	1	0.152	$110,000	$0
Salamander Pond	1.No action.	1	0.011	$0	$0
Salamander Pond	2.Restore to natural topography, (Fill)	0	0.157	$326,000	$0
Wood Duck Pond	1.Manage wetland as a "wetland" (static water) and do nothing,	1	0.040	$0	$20,500
Wood Duck Pond	2.Restore wetland back to natural hydrology. Install bottomless pipe arch culvert	0	0.037	$70,000	$90,000
Wood Duck Pond	3.Remove Center Dike & install 1 agridrain at NE corner	0	0.037	$91,995	$20,500
Bluegill Pond	1.Restore wetland back to natural hydrology. (remove wcs and dike)	1	0.157	$7,150	$0
Bluegill Pond	2.No active management	0	0.019	$0	$0
Bluegill Pond	3.Manage wetland as a "wetland" (dynamic water levels)	0	0.111	$3,000	$18,800
Clay Pit Pool (Basin)	1.No action.	1	0.059	$0	$0
Clay Pit Pool (Basin)	2.Restore to natural topography, (fill gravel pit)	0	0.152	$130,000	$0

12. Resulting Portfolio

Wetland	Management Action
Millrace Pond	Restore wetland back to natural hydrology. Install bottomless pipe arch culverts
Dragonfly Pond	Restore to natural topography, (fill gravel pit)
Salamander Pond	No action
Wood Duck Pond	Manage wetland as a "wetland" (static water) and do nothing,
Bluegill Pond	Restore wetland back to natural hydrology (remove water control structure and dike)
Clay Pit Pool (Basin)	No action
Duvall Pond 1	Restore wetland back to natural hydrology (remove dike)
Duvall Pond 2	Convert to green-tree reservoir (install agridrain, manage water levels & allow trees to establish)
Hance Pond 1	Convert to green-tree reservoir (use water control structure to manage water levels and allow trees to establish)
Hance Pond 2	Convert to green-tree reservoir (use water control structure to manage water levels and allow trees to establish)

Wetland	Management Action
Hobbs Pond	Convert to green-tree reservoir (install agridrain, manage water levels and allow trees to establish)
Knowles Marsh 1	Convert to green-tree reservoir (install agridrain, manage water levels and allow trees to establish)
Knowles Marsh 2	Convert to green-tree reservoir (install agridrain, manage water levels and allow trees to establish)
Knowles Marsh 3	Convert to green-tree reservoir (install agridrain, manage water levels and allow trees to establish)
Mallard	Restore wetland back to natural hydrology (install bottomless pipe arch culvert)
Patuxent Marsh	Manage as a green-tree reservoir
Schafer Farm Ponds	No action, maintain as is
Schafer Lake	No action, maintain as is
Snowden Pond	Convert to green-tree reservoir (install agridrain, manage water levels and allow trees to establish)
Sundew Pond	No action
Uhler Marsh 1	Convert to green-tree reservoir (install agridrain, manage water levels and allow trees to establish)
Uhler Marsh 2	Restore wetland back to natural hydrology (install bottomless pipe arch culvert)
Old Gravel Pit Pond	No action
Borrow Pit Ponds	Restore to natural topography (reset culverts, increase size or number of culverts)
Fire Control Pond	Convert to green-tree reservoir (install agridrain, remove water control structure, manage water levels, and plant trees)
Goose Pond	Restore wetland back to natural hydrology (open water control structure permanently)
Harding Spring Pond	Manage wetland as a “wetland” (dynamic water levels)
Lake Redington	Restore wetland back to natural hydrology (open water control structure permanently and remove spillway)
Mabbott Pond	Restore wetland back to natural hydrology (open water control structure permanently)
Bullfrog Pond	No action
Gravel Pit Pond	Restore to natural topography (fill gravel pit)
Kingfisher Pond	No action
Telegraph Swamp	Manage wetland as a "wetland" (static water) and do nothing, except maintain dike

10. Use of SDM results in the CCP

Under the management plan presented in the refuge final CCP, the refuge will select the optimum portfolio of wetland management strategies to meet revised wetland objectives as identified within this SDM process. This optimum portfolio of management strategies will have a capital and annual management costs associated with it.

Appendix 1 – Workshop Participants

Name	Agency	Email
John R. Sauer	USGS	jrsauer@usgs.gov
Nell Baldacchino	USFWS – Patuxent NRR	nell_baldacchino@fws.gov
Bill Perry	USFWS – Planning	bill_perry@fws.gov
Steve Henry	USFWS – Great Swamp NWR	steven_s_henry@fws.gov
Jim Lyons	USFWS – Migratory Birds	james_lyons@fws.gov
Christopher Wicker	USFWS – Patuxent NRR	christopher_wicker@fws.gov
Peter Blank	USGS	pblank@usgs.gov
Jennifer Hill	USFWS – Patuxent NRR	jennifer_hill@fws.gov
Nancy McGarigal	USFWS – Planning	nancy_mcgarigal@fws.gov
John French	USGS	jbfrench@usgs.gov
Nancy Morrissey	USFWS – Patuxent NRR	nancy_morrissey@fws.gov
Brad Knudsen	USFWS – Patuxent NRR	brad_knudsen@fws.gov
Melainie Steinkamp	USFWS – Atlantic Joint Venture	melainie_steinkamp@fws.gov
Hal Laskowski	USFWS – Refuges	harold_laskowski@fws.gov