Managing Habitat Availability for Freshwater Mussels at Noxubee National Wildlife Refuge

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MANAGEMENT PROBLEM

Freshwater mussel populations have been a source of growing concern, as they are the most imperiled taxa in the world (Williams et al. 2007). In North America, approximately 72% of mussel species are extinct, threatened or of special concern (Williams et al. 2007). Destruction and degradation of habitat from channelization, dredging, dams, siltation, fragmentation, and contaminants is considered the largest contributor to declines in mussel diversity and abundance (Williams et al. 2007). The introduction of invasive species, commercial exploitation, and declines in host fish populations also threaten mussel populations (Williams et al. 2007, Box and Mossa 1999). In the United States, impoundments and altering flow patterns in river systems have put additional strain on freshwater mussel diversity (Williams et al. 1992, Galbraith et al. 2010). Within the Muscle Shoals area of the Tennessee River system, for example, impoundments have been responsible for a 50% decrease of mussel species when compared to historical records (Williams et al. 1992).

This dramatic decline of freshwater mussels is especially troubling as mussels provide crucial ecosystem and cultural services. Freshwater mussels are responsible for many nutrient recycling and storage processes, substrate and food web modification, and biofiltration (Vaughn 2017). They can also act as indicators of environmental health, serve as a food source, and are important in some cultural practices (Vaughn 2017).

The potential loss of such valuable biodiversity has raised concerns about the effect of impoundments and land use conversion on mussels in the Noxubee River Watershed. Staff at the Sam D. Hamilton Noxubee National Wildlife Refuge, hereafter Noxubee NWR, have identified native freshwater mussel abundance and diversity as a concern at the refuge and have included objectives to maintain native mussel diversity and improve mussel habitat in their most recent Comprehensive Conservation Plan (CCP). While both of these objectives are laudable, it will initially be difficult to affect change in mussel diversity in the Noxubee River due to sparse historic data from the system as well as the extensive cost and time commitment of the surveys that would be necessary to fill this information gap. To avoid being paralyzed by a lack of current information, staff at the Noxubee NWR have decided to focus on the more presently achievable objective of improving mussel habitat within the confines of the refuge.

Spatial Dimensions

The scope of this decision has been limited to rivers and tributaries located within Noxubee NWR. Noxubee NWR was established in east-central Mississippi on June 14, 1940 to serve as a refuge and breeding ground for migratory birds and other wildlife. Today, Noxubee NWR spans three counties (Noxubee, Oktibbeha, and Winston) and 19,514 hectares of recovered farm land. Noxubee NWR contains two major impoundments, Bluff (486 hectares) and Loakfoma (243 hectares) Lakes, four green tree reservoirs, 16 other small impoundments, assorted wetland areas, and a mix of upland pine and hardwood forests (USFWS 2014).

Noxubee NWR is located within the Noxubee River Watershed, a sub-watershed of the Tombigbee Drainage. The refuge itself contains several kilometers of the main-stem of the Noxubee River and its smaller tributaries. The substrate within this section of the Noxubee River and tributaries is dominated by bedrock, sand, and a mud-silt mixture (Hubbard 1987). The water appears highly turbid throughout the river with the exception of the upper reaches of the main-stem. Coarse woody habitat lines many riparian areas in the watershed and bisects stream channels, helping to create series of pool-riffle-run sections. Some portions of the stream bank are heavily undercut and unstable. Freshwater mussels are present throughout the Noxubee River system and can be seen along shallow bank edges. Likewise, remnant valves can also be found along adjacent banks and bars which were historically inundated. This evidence of mussel presence is indicative of some degree of habitat suitability in the area, however information concerning the extent of mussel habitat available in the Noxubee River is unknown.

While mussel populations at Noxubee NWR are not well understood, within the larger Tombigbee Watershed 52 mussel taxa are known to exist, the highest number of taxa of any drainage in Mississippi (Jones et al. 2005). When the US Army Corps of Engineers altered the Tombigbee River and created the Tennessee-Tombigbee Waterway in 1985 at least five mussel species were extirpated and the ranges of many other mussel taxa were reduced (Jones et al. 2005). Several federally listed mussels can be found in the Tombigbee River drainage including: *Epioblasma penita, Pleurobema decisum, Lampsilis perovalis, Medionidus acutissimus*, and *Pleurobema perovatum* (Jones et al. 2005).

The spatial extent of this decision making process was limited to areas within Noxubee NWR in order to simplify implementation of any new management practices recommended. On refuge land, U.S. Fish and Wildlife Service (USFWS) staff have the sole authority to alter management strategies to achieve new objectives. Focusing efforts on this geographic area does, however, mean our decision will have a limited impact on declining mussel habitat on a larger scale.

Ecological Context

Life history limitations and habitat requirements of freshwater mussels put them at high risk after disturbances and environmental changes. Mussels are often long-lived (10-100 years) and must be 6-12 years old before they can reproduce (Vaughn and Taylor 1999). In addition, freshwater mussels tend to have low dispersal abilities and low juvenile survivorship (Galbraith et al. 2010, Vaughn and Taylor 1999). Freshwater mussels are filter feeders that form large multi-species aggregations called mussel beds (Galbraith et al. 2010, Vaughn and Taylor 1999). Most species of freshwater mussels are adapted to life in streams and rivers, although they can also be found in artificial flow areas (ditches) and wetlands with persistent standing water (lakes). Most species prefer medium to large bodies of water in areas with depths less than 3 feet. The majority are found along the shallow edges of waterbodies where warmer temperatures and additional light provide them with more food.

Due to the habitat requirements of freshwater mussels, two ways habitat might be improved at Noxubee NWR are through control of water levels to increase flood inundation, and through the addition of suitable substrate. Refuge managers have partial regulatory control of water levels throughout Noxubee NWR through a radial arm gate spillway, an accessory overflow spillway, and several water board control structures throughout the refuge. Water can be diverted from the Noxubee River, Bluff, and Loakfoma Lakes to provide wetted habitat in adjacent GTR’s and wetlands. As noted in the Spatial Dimensions section, current subrate in the Noxubee River includes bedrock, sand, and a mud-silt mixture (Hubbard 1987). Gravel may be a suitable substrate that could be added to this river system. For this process, it is assumed that there is no gravel substrate currently in the Noxubee River.

Legal, regulatory, and institutional constraints

Several federal statutes impose constraints on this decision making process at Noxubee NWR. The National Wildlife Refuge System Administration Act states that all national wildlife refuges are for the “conservation, management, and restoration of the fish, wildlife, and plant resources and their habitats for the benefit of present and future generations of Americans" (USFWS 2015). Additionally, the National Wildlife Refuge System Improvement Act of 1997 directs the management of all federal refuge lands and charges them with supporting conservation and overseeing the Nation's fish and wildlife resources (USFWS 1997). Within the context of this legislation, USFWS staff, members of the public, and various planning team members are charged with determining appropriate projects, objectives, and needs for individual refuges. A step-down management plan is then created, which details specific strategies and implementation schedules for meeting overall goals identified in a Comprehensive Conservation Plan (CCP). Actions proposed within the CCP must remain in accordance with the National Environmental Policy Act of 1969 and objectives cannot negatively affect waterfowl, threatened, or endangered species.

The CCP for Noxubee NWR includes information relevant to this decision making process. The CCP proposes a more comprehensive survey of aquatic life, including mussels (Project 4; USFWS 2014). Corresponding Objective A.7.1 and A.7.4 identify a need to maintain native species and improve mussel habitat through reducing point source pollution and maintaining coarse woody debris (USFWS 2014). While it is helpful that the Noxubee NWR CCP includes objectives for mussel habitat, strategies designed to meet these and other objectives may place restrictions on what new decisions can be implemented (USFWS 2014).

This decision making process is further complicated by the presence of federally protected species at Noxubee NWR. Upland pine forests are used by a population of Red-cockaded Woodpeckers (*Leuconotopicus borealis*), one of Mississippi's rarest endangered birds. Wood Storks (*Mycteria americana*), a federally threatened species, can be found seasonally in the refuge's wetland and marsh habitats, and Northern Long-eared Bats (*Myotis septentrionalis*), a species that has been proposed for federal listing, have also been documented. It is possible one or more of the federally listed mussel species of the Tombigbee River drainage could be found within Noxubee NWR. Federal law dictates that any decision considered in this process must not hinder or negatively impact the persistence of these protected species. Additionally, water control strategies are already being implemented to focus on managing American Alligators (*Alligator mississippiensis*) and overwintering waterfowl. As the decision made through this process to improve mussel habitat could include additional water control, that decision will need to be balanced with the effect it could have on these species. These effects could be included in the decision model, however to streamline learning the process this first year determining those effects may be reserved for future iterations of this process.

STAKEHOLDERS

The stakeholders for freshwater mussel management decisions on Noxubee NWR are the USFWS and Friends of Noxubee, a non-profit organization. While both are stakeholders, the USFWS is the only decision maker. If future actions are considered in a decision network with volunteer hours factoring into the cost analysis, the Friends of Noxubee group may become a decision maker.

OBJECTIVES

In what we hope will be the first of many decision making collaborations, we met with the stakeholders and helped them identify their fundamental objectives and develop their means objectives network (Figure 1A). To reduce the scope of this initial decision, the stakeholders agreed to focus on a subset of the initial network corresponding to one of two objective related to mussels in the CPP for Noxubee NWR (Figure 1B). The fundamental objectives of this subset were to maximize mussel habitat availability while minimizing costs to Noxubee NWR. To achieve these objectives, the stakeholders decided to focus on the physical structures that could be added to increase mussel habitat (i.e. substrate), maximizing floodplain inundation, and balancing management decisions with the time commitment that would be required for Noxubee NWR staff. Several other means objectives were considered to maximize mussel habitat availability (e.g. maximize fish hosts, minimize water pollution) and minimize costs (e.g. maximize volunteer worker hours), however these objectives were determined to be outside of what could be achieved in this first decision making process.

We hope a future collaboration will be able to incorporate our findings into the original, larger decision network with the fundamental objective of maximizing native mussel abundance and diversity. We limited of the scope of this initial collaboration in order to ease the learning curve for all involved and ensure a quick and reasonable management decision could be made while working to obtain data that will be required for future, larger-scale decision networks. In summary, two fundamental objectives were identified: 1) maximize mussel habitat availability and 2) minimize costs to Noxubee NWR. Three sub-objectives were also identified: 1) Maximize new mussel substrate, 2) Maximize Noxubee River floodplain inundation within the Noxubee NWR, and 3) Minimize hourly commitment of Noxubee NWR staff.

DECISION ALTERNATIVES

The decision alternatives to be included in our network were limited to those actions that could be implemented by the Noxubee NWR staff quickly and continued on an annual basis. These decision alternatives include 1) no change in management, 2) add gravel to 0-5% of the Noxubee River, 3) add gravel to 5-10% of the Noxubee River, 4) add gravel to 10-15% of the Noxubee River, 5) increase water release by 10%, and 6) increase water release by 20% (Figure 2). As employees of the USFWS, Noxubee NWR staff have the sole authority to implement management activities on NNWR land.

VALUATION OF OUTCOMES

Outcomes from both utility nodes of the decision network were valued using a ranking systems of all nodes feeding into the utility node such that the most desirable outcome received the highest value which was equal to the number of alternatives, and the least desirable outcome received a score of 1. The values for a given combination of outcomes was created by summing the total points value of the outcome such that the most desirable combination receives the highest score and the least desirable received the lowest. Next, to account for variation in scale between these two nodes both were scaled from 0 to 1 such that the best outcome received a score of 1 and the worst a score of 0 with intermediate outcomes receiving scores relative to the minimum and maximum. Finally, all values were multiplied by 50 to account for the fact that each node comprised 50 percent of the total utility score, such that a perfectly optimized decision would receive a score of 100.

DECISION MODEL OVERVIEW

Annual Rainfall

A unconditional probability representing the annual rainfall in inches. Probabilities parameterized based on average annual rainfall information and expert opinion (Table 1).

States: 0 to 25
25 to 50
50 to 75
75+

Current Riparian Buffers

An unconditional probability representing the current system state of riparian vegetation within 50 meters any stream or water body within Noxubee National Wildlife Refuge. Probabilities parameterized based on expert opinion (Table 2).

States: High
Moderate
Low

Future Riparian Buffers

A model component representing the likely future state of riparian vegetation within Noxubee National Wildlife Refuge. This component depends upon both current riparian buffers and floodplain inundation. Conditional probabilities were parameterized based on expert opinion (Table 3).

States: High
Moderate
Low

Floodplain Inundation

A model component representing the number of days in a year the floodplain of the waterways within the Noxubee National Wildlife Refuge are inundated. This component depends on water release and habitat management decision as well as annual rainfall. Conditional probabilities were parameterized using expert opinion (Table 4).

States: 0 to 50
50 to 100
100 to 150
150+

Gravel Habitat

A model component representing a qualitative evaluation of the future availability of gravel habitat suitable for use by mussels in the waterways of Noxubee National Wildlife Refuge. This component depends on the water release and habitat management decision. Future gravel habitat is dependent upon current gravel habitat, however, we have assumed there is no current gravel habitat along portions of the Noxubee River located in the Noxubee

NWR and chose not to include a current gravel node. Therefore future gravel will be completely dependent upon the decisions to add gravel. Conditional probabilities were parameterized using expert opinion (Table 5).

States: High
Medium
Low

Employee Time Investment

A model component representing the total number of hours per week dedicated to improving mussel habitat by Noxubee National Wildlife Refuge staff. This component depends on the water release and habitat management decision. Conditional probabilities were parameterized based on expert opinion (Table 6).

States: 0 to 5
5 to 10
10 to 15

We performed a one-way sensitivity analysis to determine how the changes in these components of the network would affect the utility value of the decision. We then created a tornado plot to show the results of the sensitivity analysis (Figure 3).

DISCUSSION

The optimal decision was to increase water release from the Noxubee National Wildlife Refuge by 20% with an scaled expected value combining our two fundamental objectives of 69.86. This decision makes sense in terms of our fundamental objectives, as additional water releases will increase floodplain inundation and expand mussel habitat while requiring a very small time commitment from Noxubee NWR staff. A sensitivity analysis further supported this reasoning and indicated that our decision model was most sensitive to employee time and floodplain inundation. Determining ways to offset staff hours (e.g. encourage volunteer efforts) and reducing uncertainty around the effect of water release on floodplain inundation should be high priorities for future planning and monitoring.

Value of the SDM process

Using the structured decision making process to solve a management problem was crucial in furthering collaboration between stakeholders, ensuring transparency in the decision making process, and identifying gaps in current monitoring data. Through this process it also became clear how even a small management decision applied to a localized geographic area can lead to a hugely complicated network with dozens of nodes. The network and decision possibilities turned out to be significantly more complicated than we realized, but it was a good exercise for the groups involved to start by building an all-encompassing network and then pare it down to what might reasonably be accomplished. Together we had to compromise to determine the most relevant variables influencing mussel habitat along the Noxubee River, and we had to narrow our focus even further when actually parameterizing the model due to the limited data available for habitat in Noxubee NWR. In order to simplify the analysis we also had to create some artificiality to the decision node by combining the decision to add gravel and the decision to increase water drawdown into one node. If those decision nodes were separated we could have more accurately quantified their impacts on the means objective nodes and utilities, however we determined that the added accuracy was not worth the added complexity. This may need to be reconsidered if a situation arose where more than two possible decisions were on the table.

Future steps and lessons learned

One lesson that became clear during the model building phase of this process was that most of the data required for the model is not currently collected at the Noxubee NWR. Information about current riparian buffers, how rainfall impacts floodplain inundation, and how floodplain inundation might change the status of future riparian buffers was all estimated in consultation with an expert on the refuge system. We hope that this collaboration through the SDM process will be the first of many and we will be able to incorporate our findings into our original, larger decision network (Figure 1A) with the fundamental objective of maximizing native mussel abundance and diversity in the Noxubee River. A future decision network should also take into account the effect that any decision might have on the management of threatened/endangered species or other species of interest in the refuge. The lack of current monitoring data will become even more of a hindrance within that larger network. Moving forward we should focus on collecting data for the nodes the sensitivity analysis deemed most important. Next, we should work with stakeholders to finalize the larger decision network and determine what other information will be the most crucial to future decision, cataloging and monitoring native mussel species and current abundances for example. This decision model was designed to decide upon an action that could be applied annually. We believe this model should be reevaluated at least every five years, in order to incorporate new information as it becomes available.

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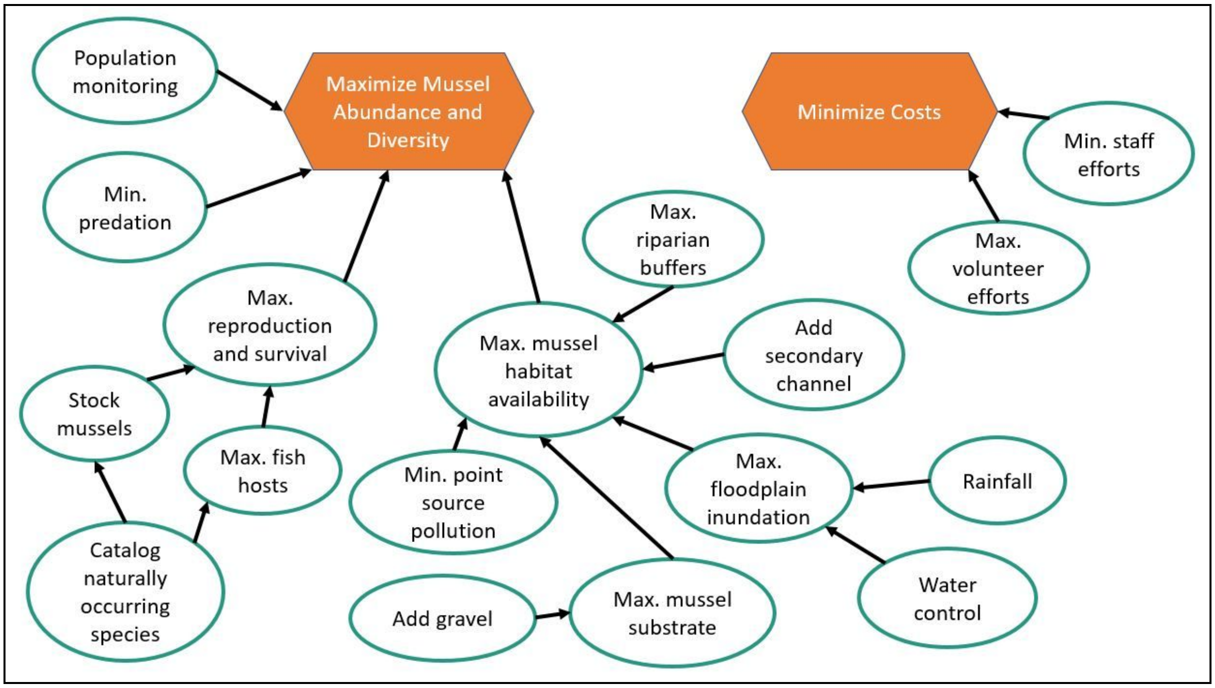
A



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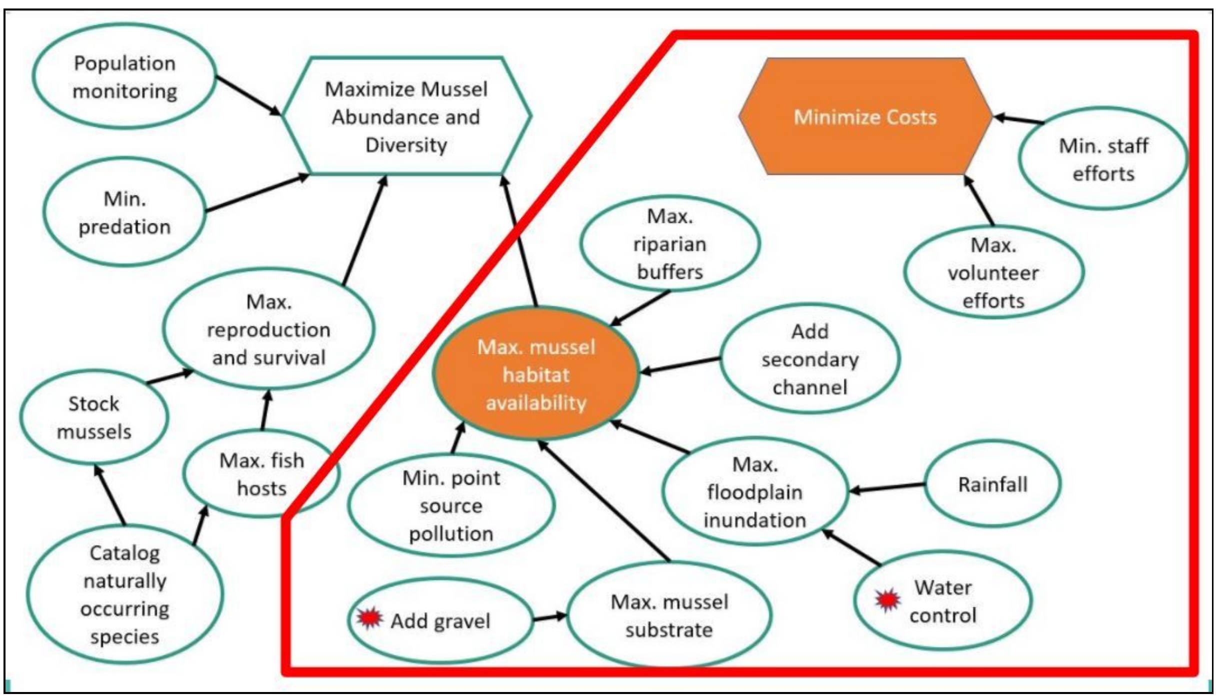

Figure 1. A) Original decision network created with stakeholders, fundamental objectives in orange. **B)** Red box identifies the subset of original decision network used during the first year of the SDM collaboration. Fundamental objectives in orange, red stars indicate where decisions fit into the network.

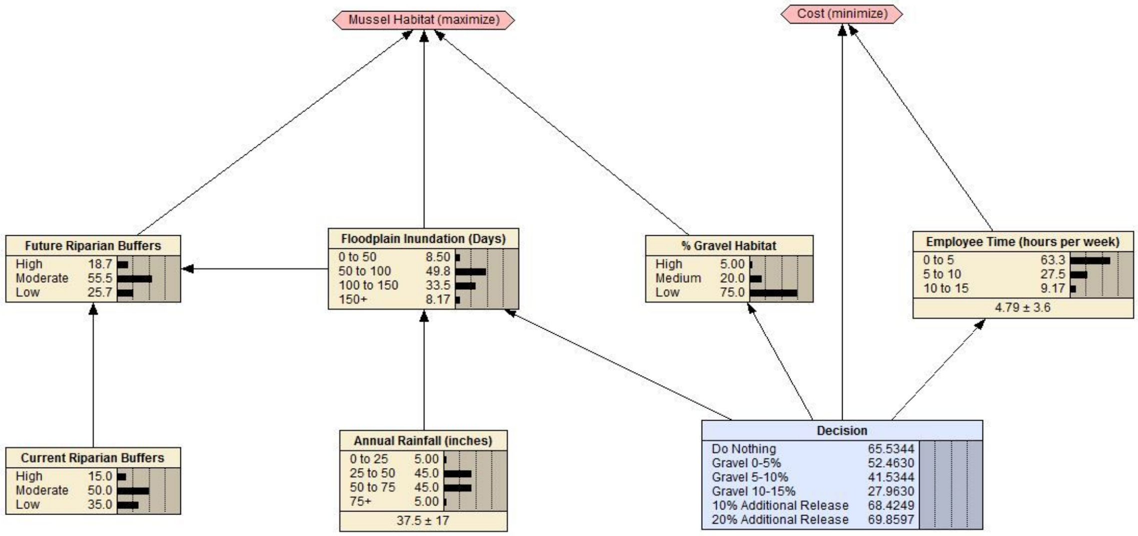

Figure 2. Decision network created in Netica.

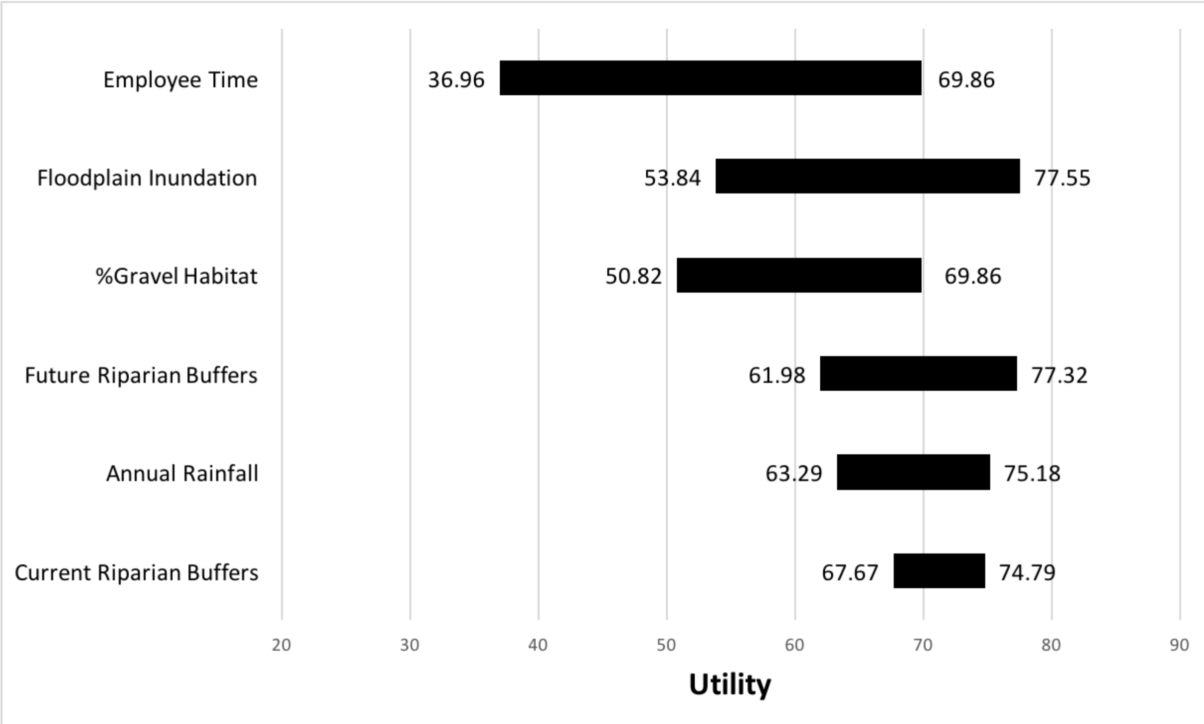

Figure 3. A tornado plot showing the one-way sensitivity analysis of decision network, which evaluates the impacts of how changes in components affect utility values.

Table 1. Unconditional probabilities (as percentages) for annual rainfall in inches used in the decision making network.

State	0 to 25	25 to 50	50 to 75	75+
Probability	5	45	45	5

Table 2. Unconditional probabilities (as percentages) for current riparian buffer used in the decision making network.

State	High	Moderate	Low
Probability	15	50	35

Table 3. Conditional probabilities (as percentages) for future riparian buffer as a function of current riparian buffers and floodplain inundation used in the decision making network.

			State	
Current Riparian Buffers	**Floodplain Inundation**	High	Moderate	Low
High	0 to 50	40	50	10
High	50 to 100	60	40	0
High	100 to 150	80	20	0
High	150+	50	50	0
Moderate	0 to 50	5	55	40
Moderate	50 to 100	10	70	20
Moderate	100 to 150	20	70	10
Moderate	150+	10	75	15
Low	0 to 50	0	5	95
Low	50 to 100	5	45	50
Low	100 to 150	15	55	30
Low	150+	0	45	55

Table 4. Conditional probabilities (as percentages) for floodplain inundation as a function of the decision and annual rainfall used in the decision making network.

		State			
Decision	**Annual Rainfall**	0 to 50	50 to 100	100 to 150	150+
Do Nothing	0 to 25	50	40	10	0
Do Nothing	25 to 50	15	65	20	0
Do Nothing	50 to 75	5	55	30	10
Do Nothing	75+	0	10	40	50
Gravel 0-5%	0 to 25	50	40	10	0
Gravel 0-5%	25 to 50	15	65	20	0
Gravel 0-5%	50 to 75	5	55	30	10
Gravel 0-5%	75+	0	10	40	50
Gravel 5-10%	0 to 25	50	40	10	0
Gravel 5-10%	25 to 50	15	65	20	0
Gravel 5-10%	50 to 75	5	55	30	10
Gravel 5-10%	75+	0	10	40	50
Gravel 10-15%	0 to 25	50	40	10	0
Gravel 10-15%	25 to 50	15	65	20	0
Gravel 10-15%	50 to 75	5	55	30	10
Gravel 10-15%	75+	0	10	40	50
10% Additional Release	0 to 25	35	50	15	0
10% Additional Release	25 to 50	5	45	45	5
10% Additional Release	50 to 75	0	40	50	10
10% Additional Release	75+	0	0	50	50
20% Additional Release	0 to 25	20	60	20	0

20% Additional Release	25 to 50	0	40	55	5
20% Additional Release	50 to 75	0	25	60	15
20% Additional Release	75+	0	0	45	55

Table 5. Conditional probabilities (as percentages) for percent gravel habitat as a function of decision used in the decision making network.

	State		
Decision	High	Medium	Low
Do Nothing	0	0	100
Gravel 0-5%	0	20	80
Gravel 5-10%	10	50	40
Gravel 10-15%	20	50	30
10% Additional Release	0	0	100
20% Additional Release	0	0	100

Table 6. Conditional probabilities (as percentages) for employee time commitment as a function of the decision used in the decision making network.

	State		
Decision	0 to 5	5 to 10	10 to 15
Do Nothing	100	0	0
Gravel 0-5%	60	35	5
Gravel 5-10%	20	70	10
Gravel 10-15%	0	60	40
10% Additional Release	100	0	0
20% Additional Release	100	0	0