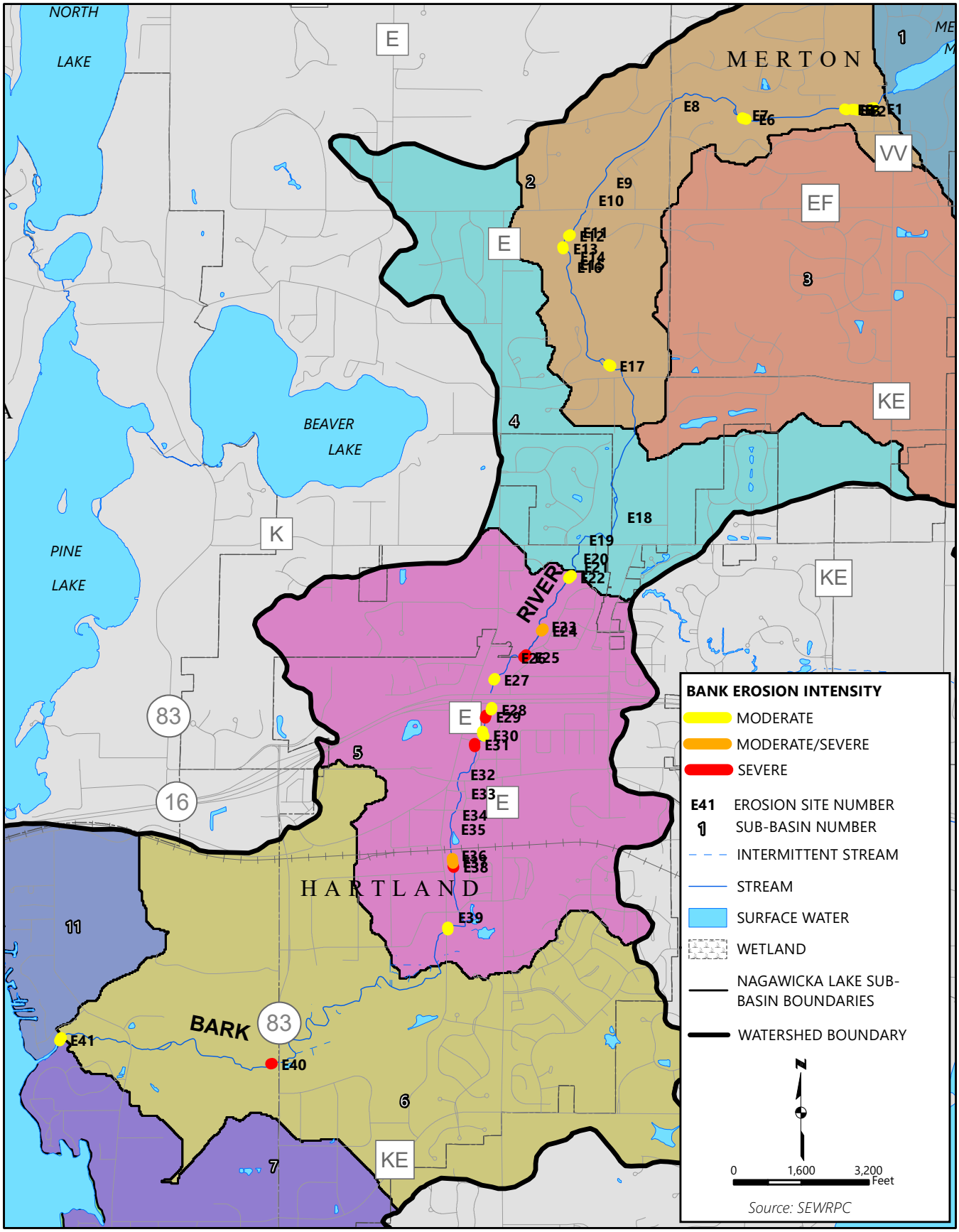
APPENDICES

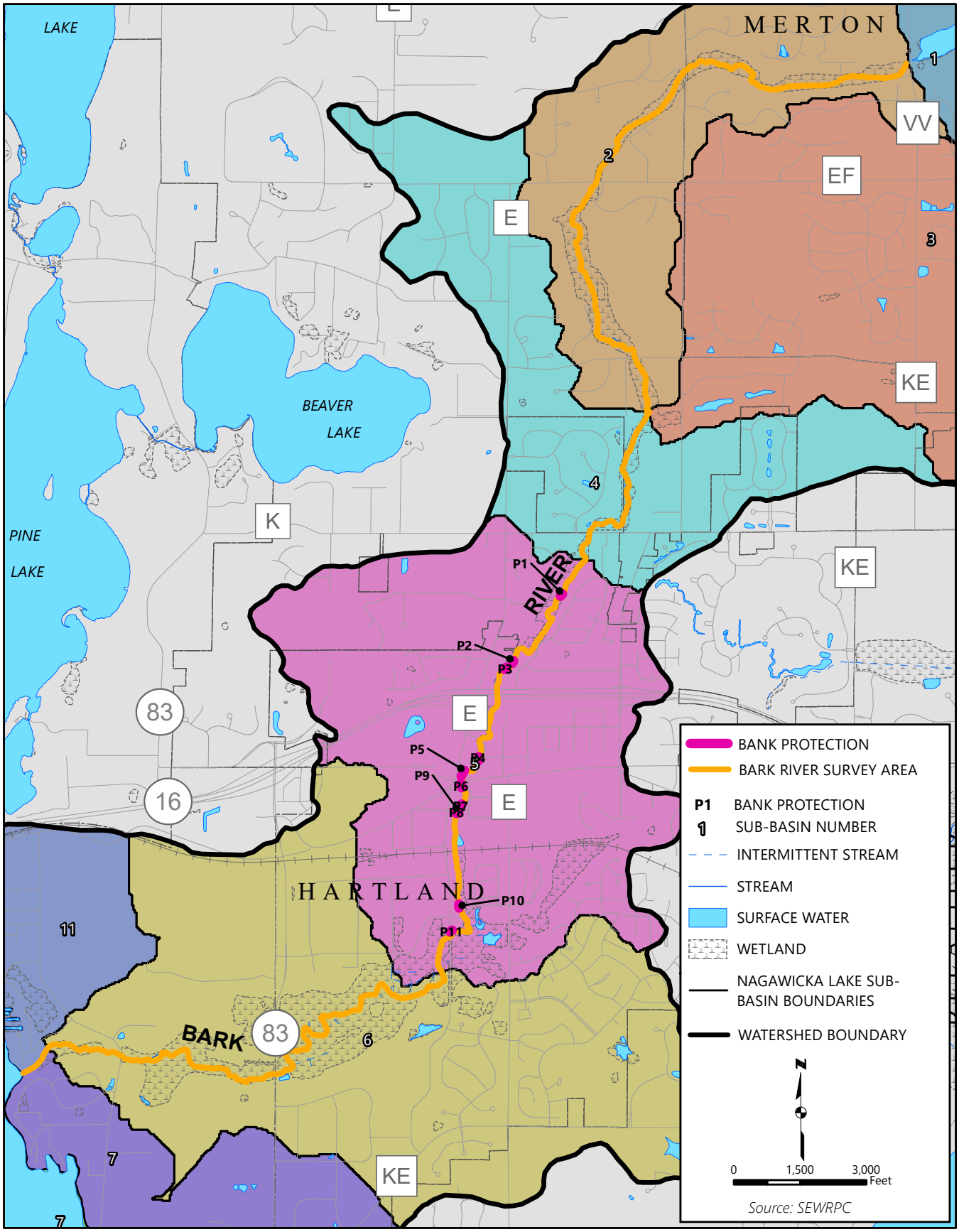
APPENDIX A

BARK RIVER SURVEY DATA

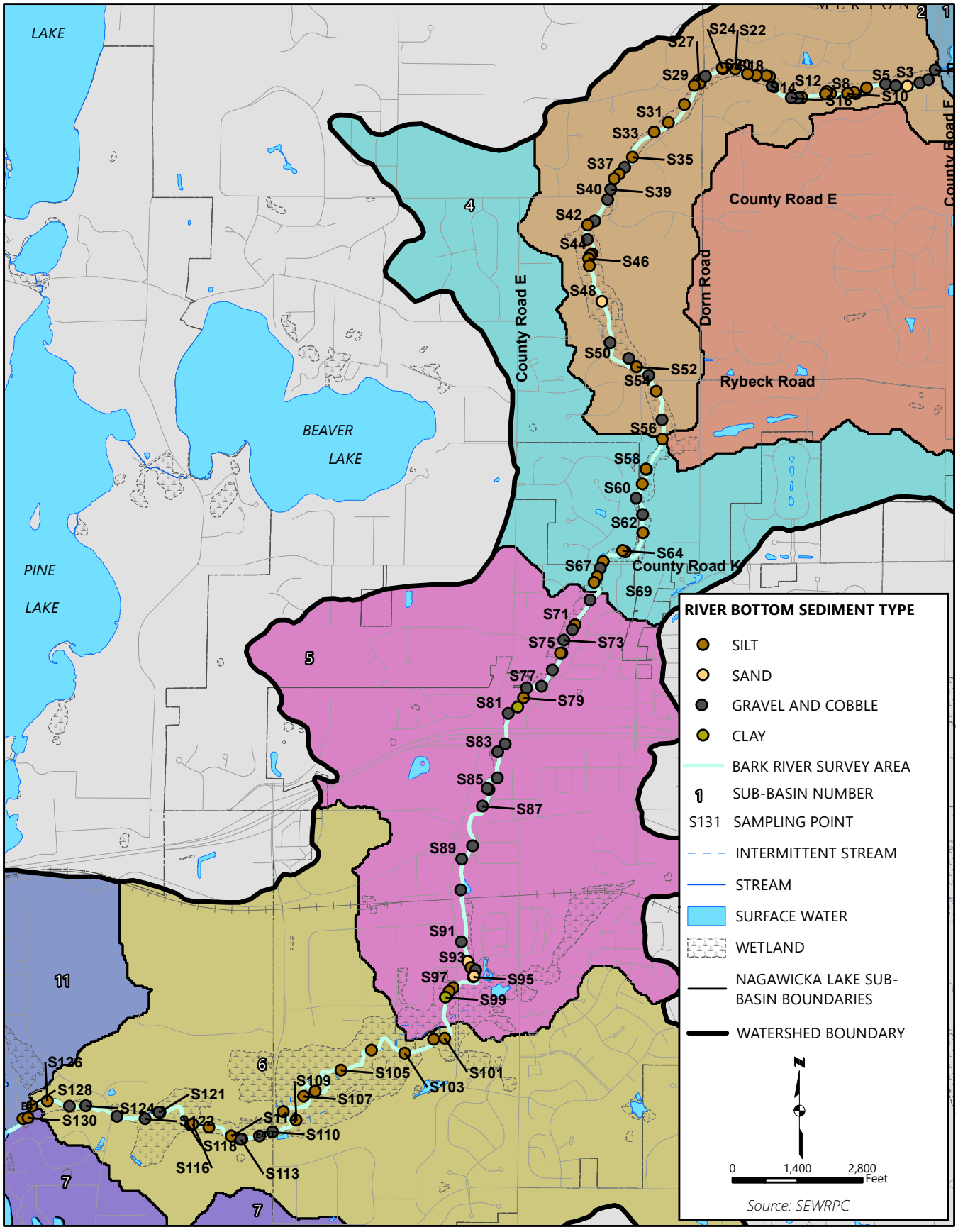
Map A.1
Areas of Bank Erosion Found During the September 2016 Bark River Survey



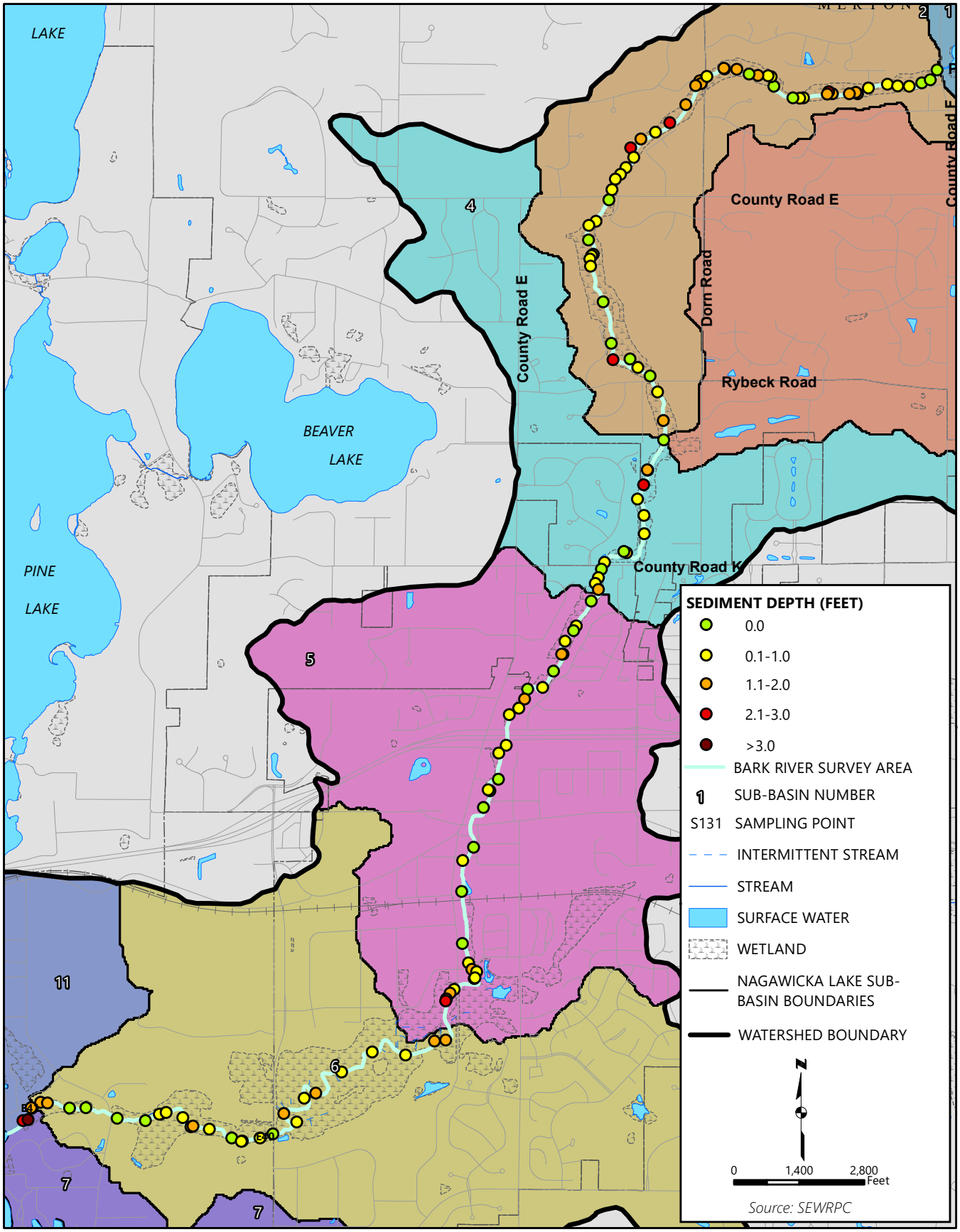
Map A.2
Bank Protection Located During Bark River Survey: September 2016



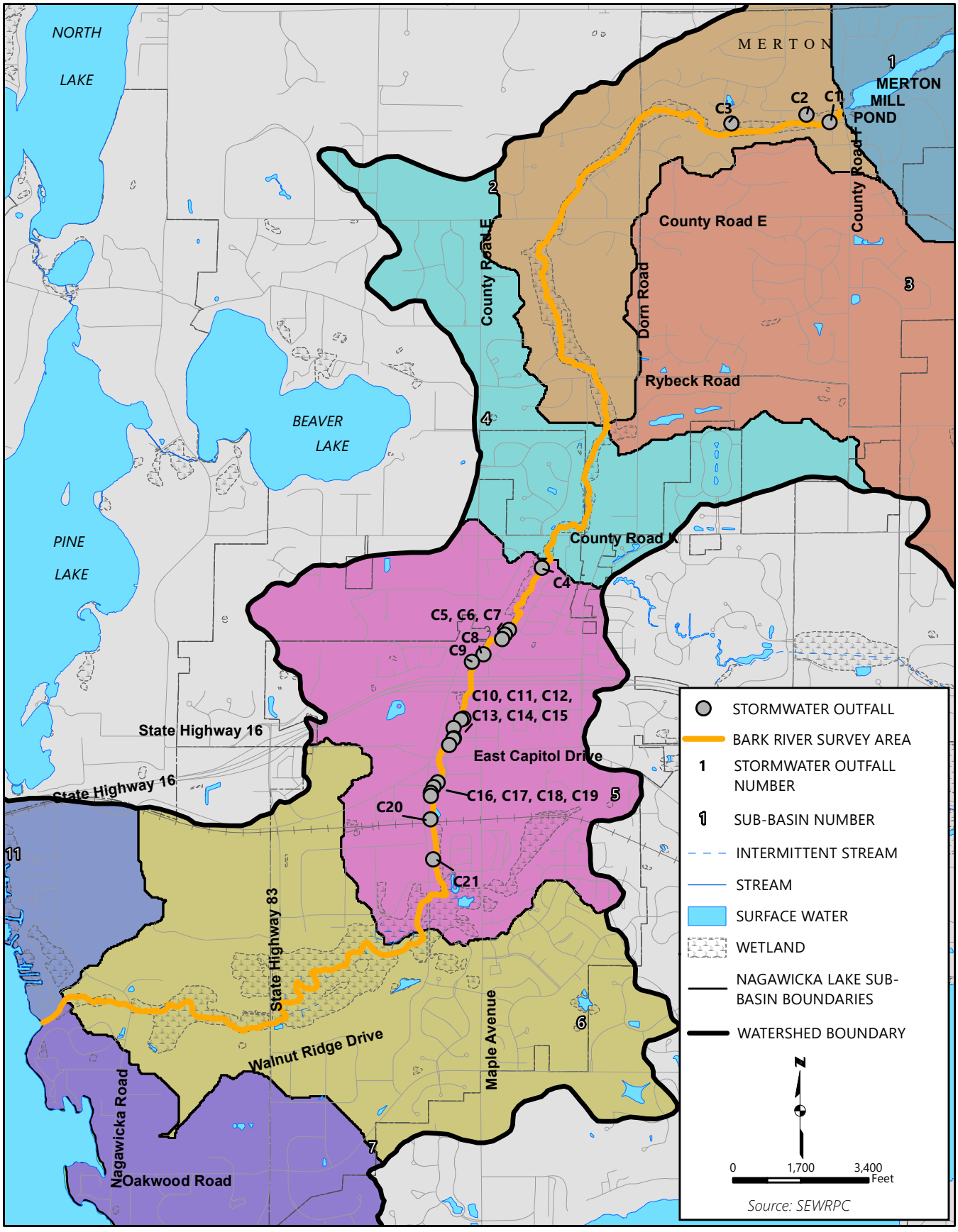
Map A.3
Bark River Bottom Sediment Types: September 2016



Map A.4
Bark River Bottom Sediment Depth: September 2016



Map A.5
Stormwater Outfalls Along the Bark River: September 2016



Map A.6
Channel Obstructions Along Bark River: September 2016

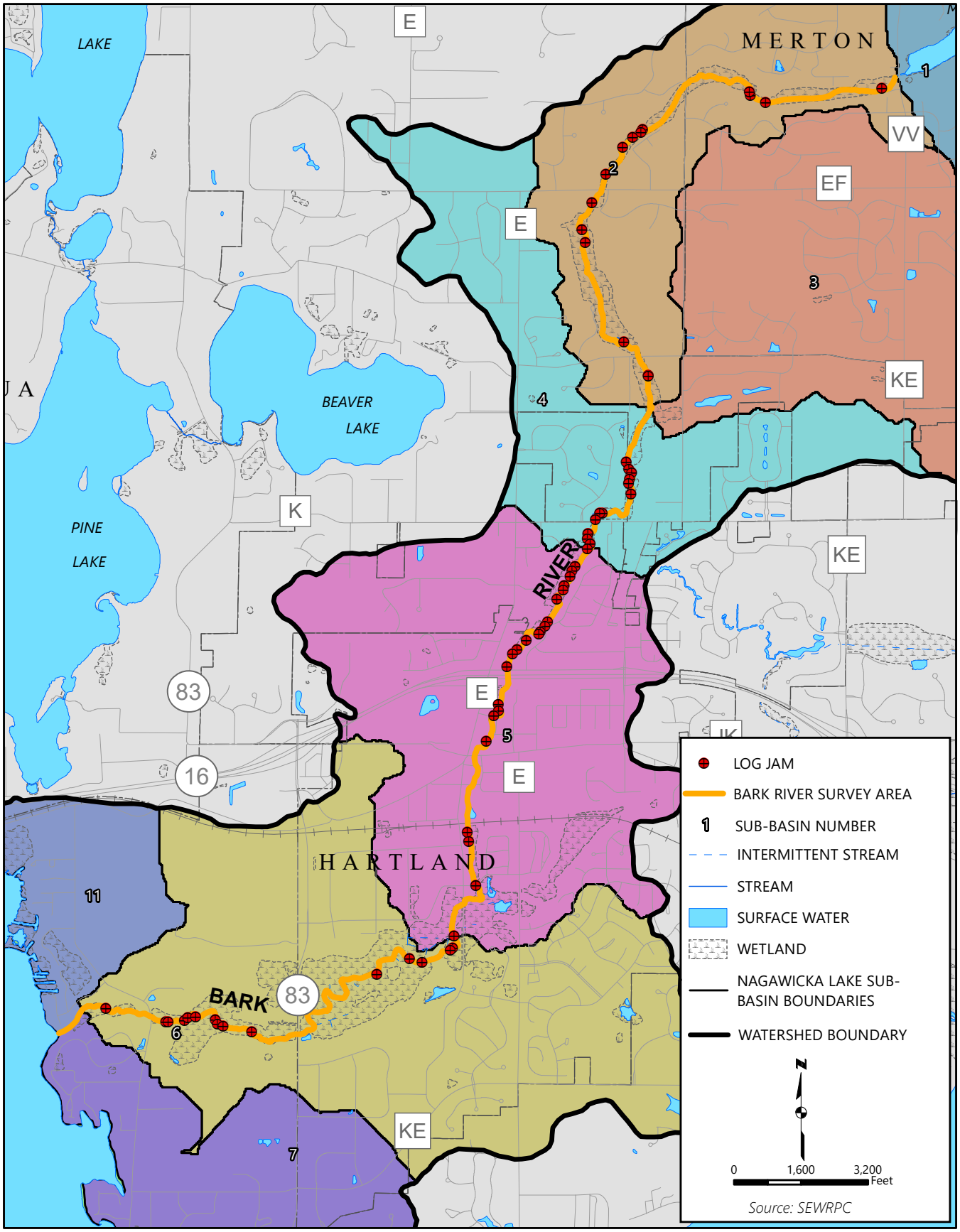


Table A.1
Potential Actively Eroding Sites Located During Bark River Survey: September 2016

Map Label	Bank	Minimum Height (feet)	Maximum Height (feet)	Depth of Undercut (feet)	Notes	Photo Description	Length (feet)
E1	Left	1.4	1.7	0.4	0.1 to 0.7 ft range undercutting on bank	Cobble and roots in loam	71.34
E2	Left	1.0	2.0	0.0	Natural erosion exposed roots and overhanging vegetation	Natural erosion and undercutting no photo though	86.66
E3	Left	0.5	0.9	1.0	Some type of protective material failing	Undercutting and looks like maybe attempt was made to fix before	80.03
E4	Both	0.5	1.5	0.2		Exposed tree roots and cobble	41.38
E5	Left	0.5	2.0	0.3		Very flat area of erosion	61.02
E6	Left	1.0	1.5	0.3	Undercut only in small spots	Natural erosion area	68.94
E7	Right	0.5	1.5	0.5		Very mild erosion	34.08
E8	Left	2.5	7.0	0.0		Bank next to roadway could have more vegetation for buffering	61.38
E9	Left	0.5	2.5	0.3		Light erosion and rip rap for protection	158.42
E10	Right	1.2	2.1	0.6		Mild undercutting in clay and loam	52.27
E11	Left	0.8	1.8	0.4	0.2 to 2.6 ft undercut range	mild erosion and exposed tree roots into loam	102.02
E12	Right	1.0	1.5	0.6		Mild erosion and undercutting	60.24
E13	Left	3.0	5.0	0.0		Most severe erosion but for short distance	39.62
E14	Right	0.5	3.5	0.6		Concentrated area of erosion	68.70
E15	Both	0.5	1.5	0.2		Consistent with exposed roots and mild undercut	95.88
E16	Left	1.4	0.0	0.0		Short area with exposed roots	50.52
E17	Right	1.0	2.0	0.0	Exposed roots no undercutting	Very mild with some root exposure	55.13
E18	Left	0.5	3.0	0.0		Concentrated area of root exposure	166.40
E19	Left	2.0	3.0	0.0		No picture	64.87
E20	Right	2.0	3.0	0.2		Very flat area of erosion	73.42
E21	Right	1.5	2.0	0.2		Eroded area with root exposure and falling tree	123.96
E22	Right	5.0	8.0	0.0		Tall scoured area but covered with vegetation and moss	108.40
E23	Left	0.0	0.0	0.2	Light erosion and undercutting	marsh area	115.29
E24	Left	0.0	0.0	0.2	Mild erosion and undercutting	Natural erosion in marsh area	86.52
E25	Right	0.5	1.0	0.6		Mild erosion	31.36
E26	Left	0.8	2.4	0.0		Very short and no photo was taken	27.70
E27	Left	1.5	3.0	0.9		Very mild erosion with vegetation	93.29
E28	Left	1.4	1.9	0.1		Scouring and lots of tree roots	83.29
E29	Left	0.5	2.0	0.5	Exposed roots	Mostly mild with area of clear undercutting and root exposure	91.96
E30	Left	0.0	3.5	0.4		Erosion and undercutting under ferns	32.43

Table continued on next page.

Table A.1 (Continued)

Map Label	Bank	Minimum Height (feet)	Maximum Height (feet)	Depth of Undercut (feet)	Notes	Photo Description	Length (feet)
E31	Both	0.5	1.6	0.7	Undercut range 0.2-1.8 ft	Mild undercutting in loam	135.51
E32	Right	0.5	3.5	4.5		Severe undercutting and exposed roots	22.13
E33	Right	0.7	1.2	0.8		Mild undercutting into clay and loam	105.52
E34	Right	1.0	1.2	0.6		Mild undercutting in clay and loam	29.51
E35	Left	1.0	1.8	0.4	0.2 to 0.8 ft undercut		86.20
E36	Left	0.0	0.0	1.2		Natural erosion into muck	3.70
E37	Left	0.5	1.0	0.2		Mild erosion and undercutting	44.70
E38	Right	0.5	1.5	0.5		Mild erosion and undercutting	56.36
E39	Right	0.5	1.0	0.0		Area of concentrated erosion and exposed roots channelized	73.81
E40	Both	0.5	1.0	0.2		Mostly mild with a concentrated spot of more severe erosion	136.05
E41	Left	1.0	1.8	0.3		Small area of mild erosion	26.70

Figure A.1
Potential Actively Eroding Sites of Concern: September 2016

Dimensions
Average Height: 1.6 feet
Length: 71 feet

Dimensions
Average Height: 1.1 feet
Length: 135 feet

Dimensions
Average Height: 1.7 feet
Length: 52 feet

Figure A.1 (Continued)

Dimensions
Average Height: 1.3 feet
Length: 100 feet

Dimensions
Average Height: 1.3 feet
Length: 60 feet

Dimensions
Average Height: 4.0 feet
Length: 40 feet

Figure A.1 (Continued)

Dimensions
Average Height: 2.0 feet
Length: 68 feet

Dimensions
Average Height: 1.0 feet
Length: 95 feet

Dimensions
Average Height: 2.5 feet
Length: 73 feet

Dimensions
Average Height: 1.7 feet
Length: 83 feet

Figure A.1 (Continued)

Dimensions
Average Height: 0.7 feet
Length: 50 feet

Dimensions
Average Height: 1.5 feet
Length: 55 feet

Dimensions
Average Height: 1.3 feet
Length: 90 feet

Dimensions
Average Height: 1.8 feet
Length: 55 feet

Figure A.1 (Continued)

Dimensions
Average Height: 0.7 feet
Length: 80 feet

Dimensions
Average Height: 1.8 feet
Length: 120 feet

Figure A.1 (Continued)

Dimensions
Average Height: 1.8 feet
Length: 32 feet

A photograph was not taken during the survey.

Dimensions
Average Height: 2.5 feet
Length: 65 feet

E39

A photograph was not taken during the survey.

Dimensions
Average Height: 1.5 feet
Length: 85 feet

E41

Dimensions
Average Height: 2.0 feet
Length: 22 feet

Table A.2
Shoreline Protection Located During Bark River Survey: September 2016

Map Label	Bank	Type	Minimum Height (feet)	Maximum Height (feet)	Average Height (feet)	Notes	Length	Summary
P1	Right	Restoration Project	3.0	3.0	3.0		69.96	Bio
P2	Right	Restoration Project	2.1	2.1	2.1	Biologs	66.58	Bio
P3	Right	Restoration Project	2.3	2.4	2.3	Biologs or bags	63.12	Bio
P4	Right	Other	0.5	2.5	1.5	Stone failing falling apart in some spots	118.76	Rip rap
P5	Left	Rip Rap	0.5	1.5	1.0		153.61	Wall
P6	Left	Other	2.0	4.0	3.0	Stone wall	112.99	Wall
P7	Right	Rip Rap	0.4	1.5	1.0		72.98	Rip rap
P8	Left	Other	5.0	5.0	5.0	Stone wall failing in spots	30.55	Wall
P9	Right	Restoration Project	3.0	4.0	3.5	Biologs	80.35	Bio
P10	Both	Rip Rap	1.0	2.5	1.7	Large boulders	94.81	Rip rap
P11	Left	WPA Wall	5.5	5.5	5.5		71.51	Wall

Figure A.2
Shoreline Protection Site Photographs: September 2016

Figure A.2 (Continued)

Figure A.2 (Continued)

Table A.3
Bark River Sediment Survey Points: September 2016

Map Label	Water Depth (feet)	Water Plus Sediment Depth (feet)	Sediment Depth (feet)	Notes
S1	0.7	0.7	0.0	Gravel
S2	0.6	0.6	0.0	Gravel shallow riffle
S3	2.6	2.6	0.0	Gravel and cobble
S4	0.7	1.0	0.3	Sand and gravel
S5	1.2	1.4	0.2	Gravel
S6	1.4	1.5	0.1	Gravel and fist to head size cobble
S7	1.1	1.3	0.2	Silt over gravel sparse coontail around
S8	1.1	2.3	1.2	Silt buildup
S9	0.9	2.1	1.2	Sediment build up on right bank
S10	1.0	2.1	1.1	Sediment buildup across river
S11	1.1	2.7	1.6	Sediment buildup
S12	1.0	3.7	2.7	Silt deposit across river
S13	1.8	2.9	1.1	Silt deposit lessens
S14	1.0	1.2	0.2	Silt over clay first break from deep deposits upstream
S15	1.4	1.5	0.1	Gravel
S16	0.5	0.5	0.0	Gravel rock riffle
S17	1.1	1.1	0.0	Gravel and large boulders
S18	1.3	1.6	0.3	Silt over gravel
S19	0.9	1.7	0.8	Silt buildup
S20	1.1	2.7	1.6	Silt buildup across river
S21	2.4	2.4	0.0	Silt over head size rock
S22	1.7	2.8	1.1	Silt deposit
S23	1.5	1.6	0.1	Silt over gravel nice plant beds
S24	1.0	2.9	1.9	Silt over rock
S25	1.2	1.3	0.1	Gravel and moderate aquatic plant beds
S26	1.8	2.0	0.2	Gravel and cobble
S27	0.6	1.7	1.1	Silt deposits along right bank
S28	1.1	2.3	1.2	Silt deposit continues
S29	0.7	2.3	1.6	Silt very thick
S30	0.6	1.9	1.3	Silt deposits
S31	1.4	3.8	2.4	Silt deposit continues
S32	2.8	2.9	0.1	Silt over gravel
S33	0.8	2.6	1.8	
S34	0.7	3.0	2.3	
S35	2.7	2.9	0.2	Silt over gravel large boulders 1 to 2 ft across
S36	2.2	2.3	0.1	Gravel
S37	1.3	1.7	0.4	Silt over rock
S38	2.3	2.9	0.6	Silt over rock
S39	2.5	2.6	0.1	Gravel and rock
S40	1.1	1.1	0.0	Gravel and cobble
S41	1.5	1.6	0.1	Gravel cobble
S42	0.8	1.6	0.8	Silt on left bank
S43	1.3	1.3	0.0	Gravel and cobble
S44	1.8	2.3	0.5	Silt and gravel
S45	0.9	1.8	0.9	Silt
S46	2.9	3.1	0.2	Silt and gravel some larger rocks
S47	1.7	2.6	0.9	Silt
S48	1.2	1.2	0.0	Sandy gravel cobble
S49	1.0	1.0	0.0	Gravel cobble sand
S50	0.7	3.4	2.7	Big pool area with lily pads and coontail silt
S51	1.3	1.3	0.0	Gravel and foot wide rocks
S52	1.0	1.1	0.1	Silt gravel cobble

Table continued on next page.

Table A.3 (Continued)

Map Label	Water Depth (feet)	Water Plus Sediment Depth (feet)	Sediment Depth (feet)	Notes
S53	1.8	1.8	0.0	Gravel cobble
S54	1.5	1.8	0.3	Silt over gravel
S55	1.6	2.9	1.3	Firm not easy to push in
S56	1.2	1.2	0.0	Silt over gravel and large stones
S57	1.5	2.4	0.9	Silt
S58	1.0	2.6	1.6	Silt deposit along left bank
S59	1.0	3.3	2.3	Wider area more silt deposited very calm current
S60	2.0	2.1	0.1	Gravel
S61	1.5	1.6	0.1	Fist to head size cobble
S62	1.3	2.1	0.8	Silt
S63	1.3	2.4	1.1	Silt
S64	2.9	2.9	0.0	Silt over rock
S65	1.1	1.3	0.2	Silt over rock
S66	0.7	0.7	0.0	Gravel and cobble
S67	1.8	2.1	0.3	Silt over gravel
S68	0.4	1.1	0.7	Silt deposit
S69	0.6	2.2	1.6	
S70	1.3	1.3	0.0	Gravel and cobble
S71	1.6	1.7	0.1	Silt and gravel
S72	1.5	1.5	0.0	Gravel and head size cobble
S73	2.4	2.5	0.1	Gravel and cobble
S74	1.8	1.9	0.1	Silt over gravel
S75	0.6	1.8	1.2	Silt deposit along right bank
S76	1.4	1.4	0.0	Cobble gravel
S77	1.4	1.5	0.1	Gravel and cobble
S78	1.1	1.1	0.0	Gravel and cobble
S79	1.1	2.2	1.1	Sediment deposit along right bank
S80	2.8	3.1	0.3	Clay
S81	1.7	1.8	0.1	Gravel and sand
S82	0.8	0.9	0.1	Gravel and cobble
S83	1.9	2.5	0.6	Gravel
S84	2.6	2.6	0.0	Gravel
S85	0.7	1.5	0.8	Silt deposit along bank
S86	2.0	2.1	0.1	Gravel
S87	2.2	2.2	0.0	Gravel
S88	1.0	1.0	0.0	Gravel rock rapid
S89	1.4	1.5	0.1	Gravel and rocks
S90	1.6	1.6	0.0	Gravel
S91	1.0	1.0	0.0	Gravel
S92	2.2	2.3	0.1	Sand and gravel
S93	0.3	2.0	1.7	Silt and leaves LOTS of detritus
S94	1.5	1.8	0.3	Gravel
S95	1.0	1.8	0.8	Silt
S96	1.4	1.7	0.3	Sand and gravel
S97	2.5	2.8	0.3	Silt over gravel
S98	1.2	2.3	1.1	Silt over gravel
S99	4.0	4.2	0.2	Solid bottom felt clay like
S100	0.8	3.4	2.6	
S101	3.6	5.0	1.4	Greater than 5 silt and detritus
S102	1.2	2.4	1.2	Silt and a little detritus
S103	2.0	2.6	0.6	Silt
S104	2.7	3.1	0.4	Silt over clay
S105	2.9	3.2	0.3	Silt
S106	1.6	2.7	1.1	Silt over hard bottom

Table continued on next page.

Table A.3 (Continued)

Map Label	Water Depth (feet)	Water Plus Sediment Depth (feet)	Sediment Depth (feet)	Notes
S107	2.3	3.1	0.8	Silt over hard bottom
S108	1.8	3.3	1.5	Silt
S109	1.6	2.6	1.0	Silt
S110	1.1	1.1	0.0	Gravel and cobble
S111	1.6	1.9	0.3	Heavily cobbled fist size to head size
S112	1.0	3.7	2.7	Ridge of silt deposit
S113	2.7	3.0	0.3	Gravel bottom
S114	1.5	1.5	0.0	Silt gravel cobble
S115	2.2	3.2	1.0	Silt
S116	1.2	2.3	1.1	Silt
S117	1.2	1.7	0.5	Deposits of sediment along banks
S118	2.5	3.5	1.0	
S119	3.8	4.6	0.8	
S120	0.6	1.6	1.0	Silt deposit
S121	2.2	2.4	0.2	Gravel and silt no cobble
S122	1.8	1.8	0.0	Cobble
S123	1.0	1.0	0.0	Gravel and cobble
S124	1.0	1.0	0.0	Gravel and cobble
S125	1.0	1.0	0.0	Rocks cobble and gravel
S126	1.5	3.3	1.8	Silty
S127	1.6	3.0	1.4	
S128	2.1	3.2	1.1	
S129	0.4	2.7	2.3	Mucky silt
S130	0.9	4.0	3.1	Ridge of sediment toward left bank
S131	1.1	3.6	2.5	Soft silt

Table A.4
Stormwater Outfalls Located During Bark River Survey: September 2016

Map Label (pond to lake)	Bank	Type	Width	Height	Condition	Street Nearby
C1	Right	Plastic	0.5	0.5	Good	Waukesha VV and Mill Street
C2	Left	Cement	3.2	3.2	Good	Fishers Landing and Spinners Pass
C3	Right	Cement	3.0	1.8	Good	Rae Drive and Hawthorne Lane near Centennial Park
C4	Right	Cement	3.7	3.7	Good	Rae Drive and Greenway Terrace
C5	Right	Cement	1.4	1.2	Good	Rae Drive and Greenway Terrace
C6	Right	Corrugated Metal	1.4	1.4	Good	Rae Drive and Greenway Terrace
C7	Right	Corrugated Metal	2.5	1.8	Good	Rae Drive and Sunnyslope Drive
C8	Left	Corrugated Metal	2.6	2.6	Good	North Ave and Hartbrook Drive
C9	Right	Other	0.6	0.6	Intact	Lawn Street
C10	Right	Other	0.7	0.7	Good	Lawn Street
C11	Right	Corrugated Metal	2.2	2.2	Rusted and crumbling on end	Lawn Street
C12	Right	Cement	1.5	2.5	Intact	Oak Street and Lawn Street
C13	Right	Corrugated Metal	1.5	1.4	Good	Oak Street and Lawn Street
C14	Right	Cement	3.0	2.5	Broken edges but intact	Capitol Drive and Oak Street
C15	Left	Other	1.5	1.5	Fone	Cottonwood and Park Avenue
C16	Left	Corrugated Metal	1.0	1.0	Good	Cottonwood and Park Avenue
C17	Left	Corrugated Metal	1.2	1.2	Good	Cottonwood and Park Avenue
C18	Right	Corrugated Metal	1.5	1.5	Good	Cottonwood and Park Avenue
C19	Left	Corrugated Metal	4.0	4.0	Good	Cottonwood Avenue and Railroad - Nixon Park on Right Bank
C20	Left	Cement	3.0	4.0	Good	Corner of Cottonwood Avenue and Cardinal Lane

Figure A.3
Stormwater Outfall Photographs: September 2016

Bank: Right
Material: Plastic
Condition: Good
Dimensions: 0.5 x 0.5 feet

Bank: Left
Material: Iron
Condition: Good
Dimensions: Not Measured

Bank: Left
Material: Concrete
Condition: Good
Dimensions: 3.2 x 3.2 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 3.0 x 1.8 feet

Figure A.3 (Continued)

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 3.7 x 3.7 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 1.4 x 1.2 feet

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.4 x 1.4 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 1.4 x 1.2 feet

Figure A.3 (Continued)

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.4 x 1.4 feet

Bank: Right
Material: Plastic
Condition: Good
Dimensions: 0.6 x 0.6 feet

Bank: Right
Material: Plastic
Condition: Good
Dimensions: 0.7 x 0.7 feet

Bank: Right
Material: Corrugated Steel
Condition: Rusted and Cracking
Dimensions: 2.2 x 2.2 feet

Figure A.3 (Continued)

Bank: Right
Material: Concrete
Condition: Cracked
Dimensions: 1.5 x 1.5 feet

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.5 x 1.4 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 3.0 x 2.5 feet

Bank: Left
Material: Plastic
Condition: Good
Dimensions: 1.5 x 1.5 feet

Figure A.3 (Continued)

Bank: Left
Material: Corrugated Steel
Condition: Good
Dimensions: 1.0 x 1.0 feet

Bank: Left
Material: Corrugated Steel
Condition: Good
Dimensions: 1.2 x 1.2 feet

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.5 x 1.5 feet

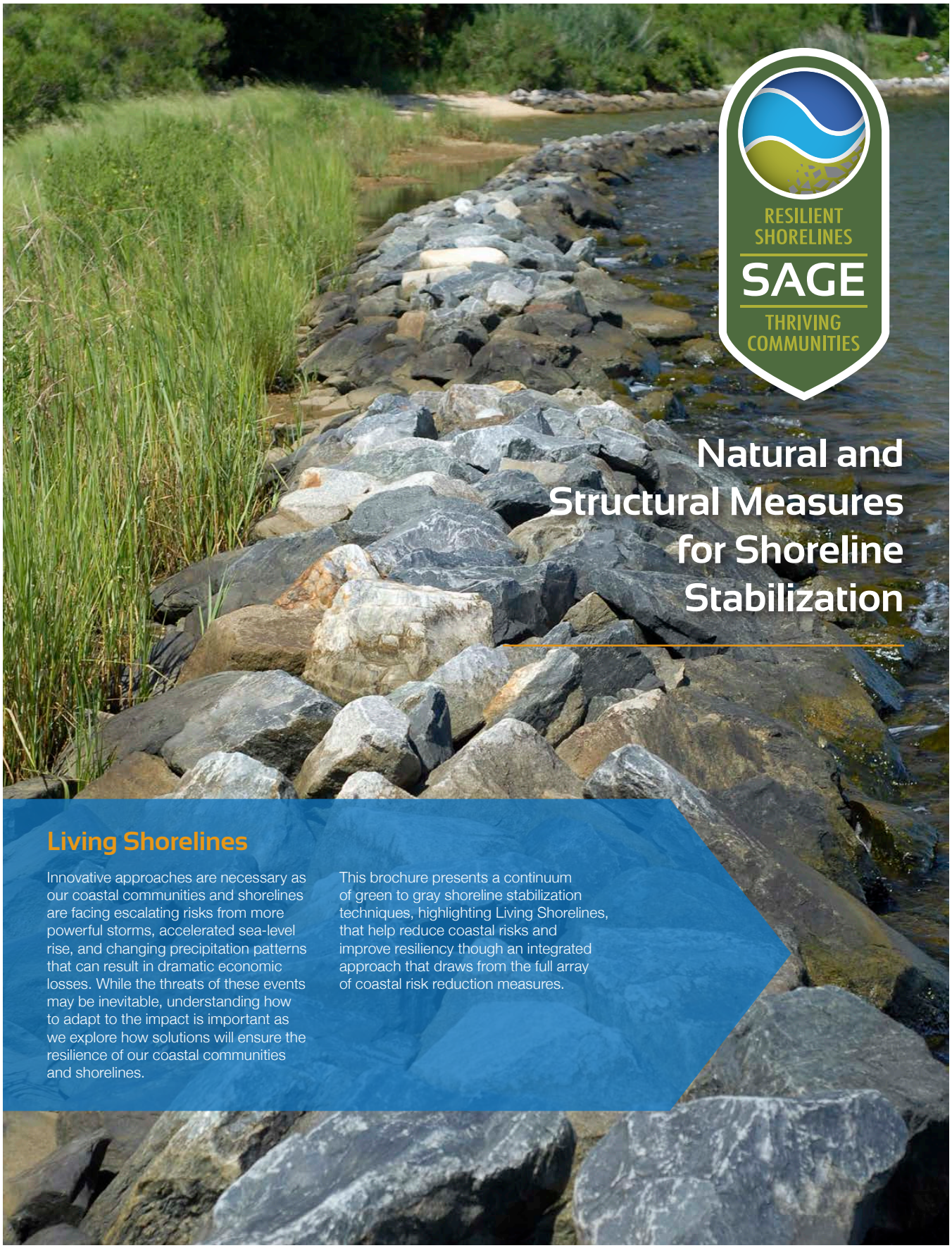
Figure A.3 (Continued)

Bank: Left
Material: Concrete
Condition: Good
Dimensions: 4.0 x 4.0 feet

Bank: Left
Material: Concrete
Condition: Good
Dimensions: 3.0 x 4.0 feet

NATURAL AND STRUCTURAL MEASURES FOR SHORELINE STABILIZATION

APPENDIX B



Natural and Structural Measures for Shoreline Stabilization

Living Shorelines

Innovative approaches are necessary as our coastal communities and shorelines are facing escalating risks from more powerful storms, accelerated sea-level rise, and changing precipitation patterns that can result in dramatic economic losses. While the threats of these events may be inevitable, understanding how to adapt to the impact is important as we explore how solutions will ensure the resilience of our coastal communities and shorelines.

This brochure presents a continuum of green to gray shoreline stabilization techniques, highlighting Living Shorelines, that help reduce coastal risks and improve resiliency though an integrated approach that draws from the full array of coastal risk reduction measures.

Coastal Risk Reduction and Living Shorelines

Coastal Risk Reduction

Coastal systems typically include both natural habitats and man-made structural features. The relationships and interactions among these features are important variables in determining coastal vulnerability, reliability, risk and resilience.

Coastal risk reduction can be achieved through several approaches, which may be used in combination with each other. Options for coastal risk reduction include:

- Natural or nature-based measures: Natural features are created through the action of physical, biological, geologic, and chemical processes operating in nature, and include marshes, dunes and oyster reefs. Nature-based features are created by human design, engineering, and construction to mimic nature. A living shoreline is an example of a nature-based feature.
- Structural measures: Structural measures include sea walls, groins and breakwaters. These features reduce coastal risks by decreasing shoreline erosion, wave damage, and flooding.
- Non-structural measures: Includes modifications in public policy, management practices, regulatory policy and pricing policy (e.g., structure acquisitions or relocations, flood proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, emergency response plans).

The types of risk reduction measures employed depend upon the geophysical setting, the desired level of risk reduction, objectives, cost, reliability, and other factors.

SAGE – Systems Approach to Geomorphic Engineering

USACE and NOAA recognize the value of an integrated approach to risk reduction through the incorporation of natural and nature-based features in addition to non-structural and structural measures to improve social, economic, and ecosystem resilience. To promote this approach, USACE and NOAA have engaged partners and stakeholders in a community of practice called SAGE, or a Systems Approach to Geomorphic Engineering. This community of practice provides a forum to discuss science and policy that can support and advance a systems approach to implementing risk reduction measures that both sustain a healthy environment and create a resilient shoreline.

SAGE promotes a hybrid engineering approach that integrates soft or 'green' natural and nature-based measures, with hard or 'gray' structural ones at the landscape scale. These stabilization solutions include "living shoreline" approaches which integrate living components, such as plantings, with structural techniques, such as seawalls or breakwaters.

Living Shorelines achieve multiple goals, such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage;
- Providing ecosystem services (such as habitat for fish and other aquatic species) and increasing flood storage capacity; and
- Maintaining connections between land and water ecosystems to enhance resilience.

In order to determine the most appropriate shoreline protection technique, several site-specific conditions must be assessed. The following coastal conditions, along with other factors, are used to determine the combinations of green and gray solutions for a particular shoreline.

REACH: A longshore segment of a shoreline where influences and impacts, such as wind direction, wave energy, littoral transport, etc. mutually interact.

RESILIENCE: The ability to avoid, minimize, withstand, and recover from the effects of adversity, whether natural or man made, under all circumstances of use. This definition also applies to engineering (i), ecological (ii), and community resilience (iii).

FETCH: A cross shore distance along open water over which wind blows to generate waves. For any given shore, there may be several fetch distances depending on predominant wind direction.

PHYSICAL CONDITIONS: The slope of the foreshore or beach face, a geologic condition or bathymetry offshore.

TIDAL RANGE: The vertical difference between high tide and low tide.

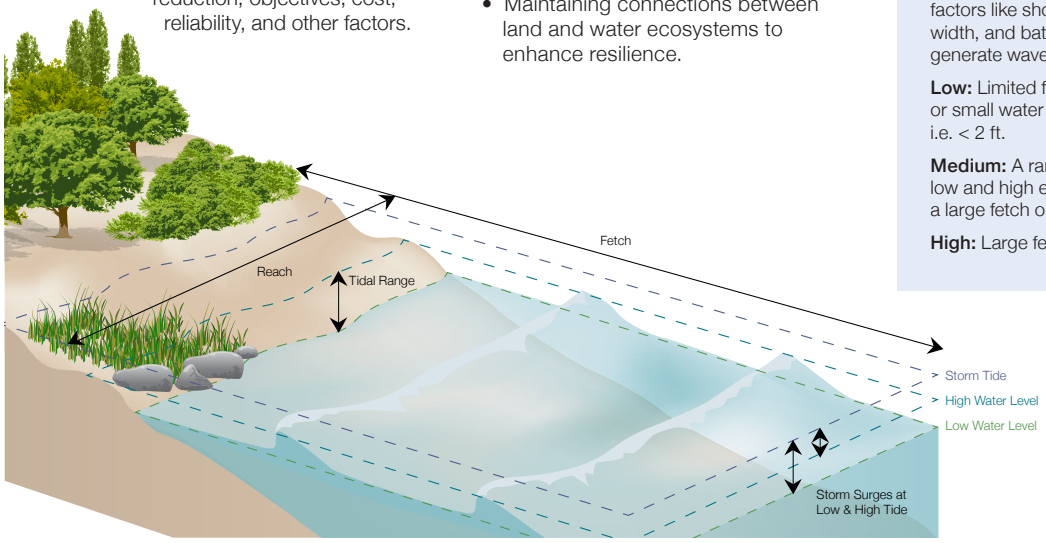
STORM SURGE: The resulting temporary rise in sea level due to the action of wind stress on the water surface and low atmospheric pressure created during storms which can cause coastal flooding. Surge is the difference from expected tide level. Storm tide is the total water level.

WAVE ENERGY: Wave energy is related to wave height and describes the force a wave is likely to have on a shoreline. Different environments will have lower or higher wave energy depending on environmental factors like shore orientation, wind, channel width, and bathymetry. Boat wakes can also generate waves.

Low: Limited fetch in a sheltered, shallow or small water body (estuary, river, bay) i.e. < 2 ft.

Medium: A range that combines elements of low and high energy (e.g., shallow water with a large fetch or partially sheltered) i.e. 2 - 5 ft.

High: Large fetch, deep water (open ocean).



HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GREEN - SOFTER TECHNIQUES

Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

LIVING SHORELINE

VEGETATION ONLY

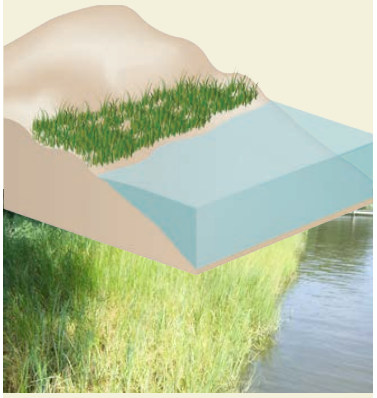


Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Roots hold soil in place to reduce erosion. Provides a buffer to upland areas and breaks small waves.

Suitable For

Low wave energy environments.

Material Options

- Native plants*

Benefits

- Dissipates wave energy
- Slows inland water transfer
- Increases natural storm water infiltration
- Provides habitat and ecosystem services
- Minimal impact to natural community and ecosystem processes
- Maintains aquatic/terrestrial interface and connectivity
- Flood water storage

Disadvantages

- No storm surge reduction ability
- No high water protection
- Appropriate in limited situations
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●
Operations & Maintenance: ●

EDGING

Photo Credit: Partnership for Delaware Estuary

Structure to hold the toe of existing or vegetated slope in place. Protects against shoreline erosion.

Suitable For

Most areas except high wave energy environments.

Vegetation* Base with Material Options

(low wave only, temporary)
- "Snow" fencing
- Erosion control blankets
- Geotextile tubes
- Living reef (oyster/mussel)
- Rock gabion baskets

Benefits

- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

Disadvantages

- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ● ●
Operations & Maintenance: ●

SILLS

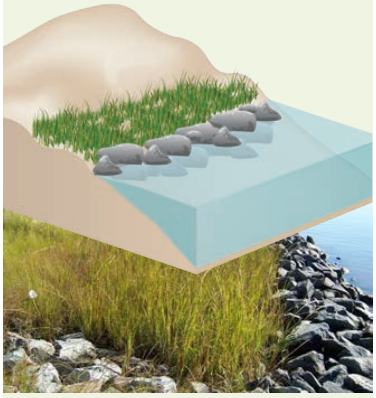


Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Parallel to existing or vegetated shoreline, reduces wave energy and prevents erosion. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

Suitable For

Most areas except high wave energy environments.

Vegetation* Base with Material Options

- Stone
- Sand breakwaters
- Living reef (oyster/mussel)
- Rock gabion baskets

Benefits

- Provides habitat and ecosystem services
- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

Disadvantages

- Require more land area
- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ● ●
Operations & Maintenance: ●

* Native plants and materials must be appropriate for current salinity and site conditions.

CONTINUED ON NEXT PAGE

Initial Construction: ● = up to $1000 per linear foot, ● ● = $1001 - $2000 per linear foot, ● ● ● = $2001 - $5000 per linear foot, ● ● ● ● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ● ● = $101 - $500 per linear foot, ● ● ● = over $500 per linear foot

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GREEN - SOFTER TECHNIQUES
Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

LIVING SHORELINE

CONTINUED FROM LAST PAGE

BEACH NOURISHMENT ONLY

Photo Credit: USACE New York District Public Affairs

Large volume of sand added from outside source to an eroding beach. Widens the beach and moves the shoreline seaward.

Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

Material Options

- Sand

Benefits

- Expands usable beach area
- Lower environmental impact than hard structures
- Flexible strategy
- Redesigned with relative ease
- Provides habitat and ecosystem services

Disadvantages

- Requires continual sand resources for renourishment
- No high water protection
- Appropriate in limited situations
- Possible impacts to regional sediment transport

Initial Construction: ●●●
Operations & Maintenance: ●●

BEACH NOURISHMENT & VEGETATION ON DUNE

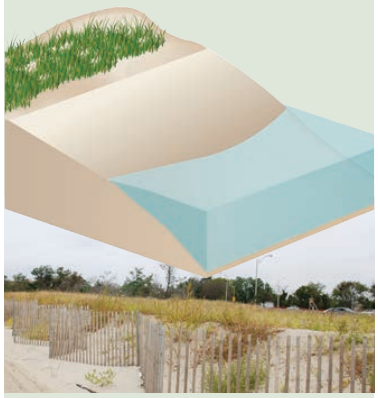


Photo Credit: USACE New York District Public Affairs

Helps anchor sand and provide a buffer to protect inland area from waves, flooding and erosion.

Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

Material Options

Sand with vegetation
Can also strengthen dunes with:
- Geotextile tubes
- Rocky core

Benefits

- Expands usable beach area
- Lower environmental impact
- Flexible strategy
- Redesigned with relative ease
- Vegetation strengthens dunes and increases their resilience to storm events
- Provides habitat and ecosystem services

Disadvantages

- Requires continual sand resources for renourishment
- No high water protection
- Appropriate in limited situations
- Possible impacts to regional sediment transport

Initial Construction: ●●●
Operations & Maintenance: ●●

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GRAY - HARDER TECHNIQUES
Large Waves | Large Fetch | Steep Slope | Open Coast

COASTAL STRUCTURE

BREAKWATER

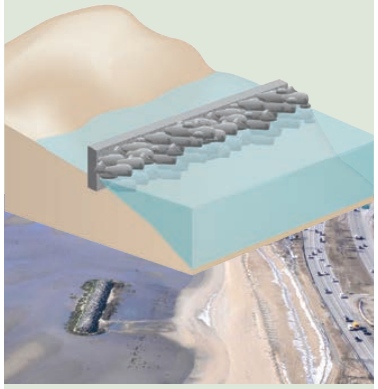


Photo Credit: USACE New York District Public Affairs

Offshore structures intended to break waves, reducing the force of wave action and encourages sediment accretion. Can be floating or fixed to the ocean floor, attached to shore or not, and continuous or segmented. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

Suitable For

Most areas except high wave energy environments often in conjunction with marinas.

Material Options

- Grout-filled fabric bags
- Armorstone
- Pre-cast concrete blocks
- Living reef (oyster/mussel) if low wave environment
- Wood
- Rock[‡]

Benefits

- Reduces wave force and height
- Stabilizes wetland
- Can function like reef
- Economical in shallow areas
- Limited storm surge flood level reduction

Disadvantages

- Expensive in deep water
- Can reduce water circulation (minimized if floating breakwater is applied)
- Can create navigational hazard
- Require more land area
- Uncertainty of successful vegetation growth and competition with invasive
- No high water protection
- Can reduce water circulation
- Can create navigation hazard

Initial Construction: ●●●●
Operations & Maintenance: ●●●

GROIN

Photo Credit: USACE New York District Public Affairs

Perpendicular, projecting from shoreline. Intercept water flow and sand moving parallel to the shoreline to prevent beach erosion and break waves. Retain sand placed on beach.

Suitable For

Coordination with beach nourishment.

Material Options

- Concrete/stone rubble[‡]
- Timber
- Metal sheet piles

Benefits

- Protection from wave forces
- Methods and materials are adaptable
- Can be combined with beach nourishment projects to extend their life

Disadvantages

- Erosion of adjacent sites
- Can be detrimental to shoreline ecosystem (e.g. replaces native substrate with rock and reduces natural habitat availability)
- No high water protection

[‡] Rock/stone needs to be appropriately sized for site specific wave energy.

Initial Construction: ●●●
Operations & Maintenance: ●●

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GRAY CAN BE GREENER: e.g., 'Living Breakwater' using oysters to colonize rocks or 'Greenwall/Biowall' using vegetation, alternative forms and materials

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GRAY - HARDER TECHNIQUES
Large Waves | Large Fetch | Steep Slope | Open Coast

COASTAL STRUCTURE

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REVETMENT

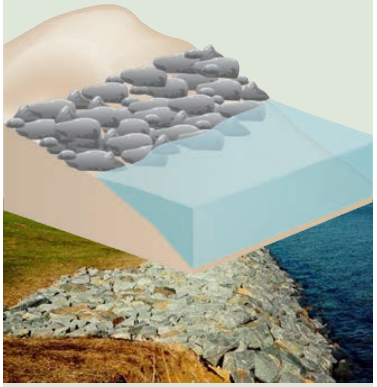


Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Lays over the slope of a shoreline. Protects slope from erosion and waves.

Suitable For

Sites with pre-existing hardened shoreline structures.

Material Options

- Stone rubble[†]
- Concrete blocks
- Cast concrete slabs
- Sand/concrete filled bags
- Rock-filled gabion basket

Benefits

- Mitigates wave action
- Little maintenance
- Indefinite lifespan
- Minimizes adjacent site impact

Disadvantages

- No major flood protection
- Require more land area
- Loss of intertidal habitat
- Erosion of adjacent unreinforced sites
- Require more land area
- No high water protection
- Prevents upland from being a sediment source to the system

[†] Rock/stone needs to be appropriately sized for site specific wave energy.

Initial Construction: ●●●●
Operations & Maintenance: ●●

BULKHEAD

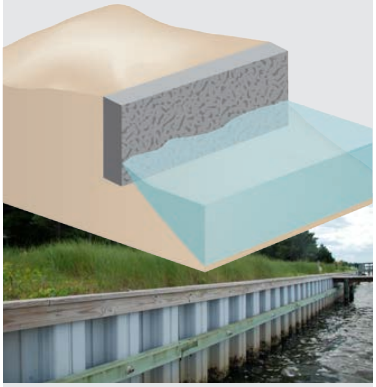


Photo Credit: North Carolina Department of Environment and Natural Resources

Parallel to the shoreline, vertical retaining wall. Intended to hold soil in place and allow for a stable shoreline.

Suitable For

High energy settings and sites with pre-existing hardened shoreline structures. Accommodates working water fronts (eg: docking for ships and ferries).

Material Options

- Steel sheet piles
- Timber
- Concrete
- Composite carbon fibers
- Gabions

Benefits

- Moderates wave action
- Manages tide level fluctuation
- Long lifespan
- Simple repair

Disadvantages

- No major flood protection
- Erosion of seaward seabed
- Erosion of adjacent unreinforced sites
- Loss of intertidal habitat
- May be damaged from overtopping oceanfront storm waves
- Prevents upland from being a sediment source to the system
- Induces wave reflection

Initial Construction: ●●●
Operations & Maintenance: ●●

SEAWALL

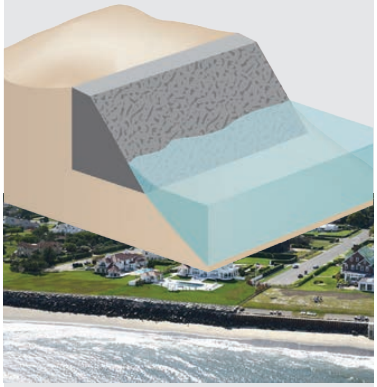


Photo Credit: USACE New York District Public Affairs

Parallel to shoreline, vertical or sloped wall. Soil on one side of wall is the same elevation as water on the other. Absorbs and limits impacts of large waves and directs flow away from land.

Suitable For

Areas highly vulnerable to storm surge and wave forces.

Material Options

- Stone
- Rock
- Concrete
- Steel/vinyl sheets
- Steel sheet piles

Benefits

- Prevents storm surge flooding
- Resists strong wave forces
- Shoreline stabilization behind structure
- Low maintenance costs
- Less space intensive horizontally than other techniques (e.g. vegetation only)

Disadvantages

- Erosion of seaward seabed
- Disrupt sediment transport leading to beach erosion
- Higher up-front costs
- Visually obstructive
- Loss of intertidal zone
- Prevents upland from being a sediment source to the system
- May be damaged from overtopping oceanfront storm waves

Initial Construction: ●●●●
Operations & Maintenance: ●●●

GRAY CAN BE GREENER: e.g., 'Living Breakwater' using oysters to colonize rocks or 'Greenwall/Biowall' using vegetation, alternative forms and materials

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

6

Is a Living Shoreline a Good Fit for What I Need?

Living Shorelines achieve multiple goals such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage
- Providing ecosystem services, such as habitat for fish and other aquatic species and increasing flood storage capacity
- Maintaining connections between land and water ecosystems to enhance resilience

Site-specific conditions will influence your choice of shoreline protection technique (ex: wave energy level, fetch lengths, rate and pattern of erosion, etc). Here are some additional factors to keep in mind as you consider Living Shorelines.

WHAT ARE THE BENEFITS?

- Erosion control and shore stabilization.
- Restored and enhanced habitat which supports fish and wildlife populations.
- Increased property values.
- Enhanced community enjoyment.
- Opportunities for education.
- Improved public access to waterfront through recreational activities such as fishing, boating and birding. Can be used to satisfy zoning and permitting requirement for waterfront development projects.
- Complemented natural shoreline dynamics & movement; increased resilience and absorption of wave energy, storm surge and floodwaters; and an adaptive tool for preparation of sea level rise.
- Improved water quality from settling or trapping sediment (e.g. once established, a marsh can filter surface water runoff or oysters can provide coastal water filtration).

WHAT ARE SOME CHALLENGES?

- Uncertainty in risk because of lack of experience of techniques.
- Public funds are often tied to government permit compliance.
- Permitting processes can be lengthy and challenging. The existing regulatory process is centered on traditional "gray" or "hard" techniques. Regulators and project sponsors alike are learning how to design living shorelines projects. Talk with someone about your state's permitting process or to hear about their experiences.
- It takes time to develop and test new shoreline protection methods.
- There may be land ownership constraints. Consider where federal and state jurisdiction for the water body starts and ends.
- In urban environments, there is limited land (bulkheads may seem like the only option), a variety of upland uses (industrial past use may have left legacy contaminants) and high velocity waters.
- The overall sediment system needs to be taken into account to protect neighboring properties from experiencing starved down drift shorelines or other consequences as a result of a project.
- Lack of public awareness of performance and benefits of living shorelines.
- Not all techniques have the same level of performance or success monitoring. Less practiced techniques may require more monitoring.

WHAT INFLUENCES COST?

- The materials chosen for the project influence cost.
- Including green techniques can be cheaper than traditional gray techniques.
- Sometimes it's possible to install the project yourself, other times you will need help from a professional.
- Long term maintenance is required as any landscape project (e.g. replanting may be needed after a storm).

HOW TO FIND OUT MORE

If you have a Living Shorelines permitting question, contact your state's office of Environmental Protection, Conservation or Natural Resources, your coastal zone manager such as your state's Department of State, as well as your local U.S. Army Corps of Engineers (USACE) district office.

If you would like science or engineering advice, or to talk to people who have experience studying or constructing living shorelines, reach out to some of the following: your local universities, your City's Department of Planning and Department of Parks, Sea Grant Chapter, Littoral Society, The Nature Conservancy, The Trust for Public Land, The Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), USACE, engineering firms and other organizations that focus on your local waterfront.

These and other websites are good references to learn more about Living Shorelines:

SAGE
www.SAGEcoast.org

NOAA Restoration
www.habitat.noaa.gov/livingshorelines

USACE Engineer Research Development Center, Engineering with Nature
el.erdc.usace.army.mil/ewn

USACE North Atlantic Division, National Planning Center of Expertise for Coastal Storm Damage Reduction
www.nad.usace.army.mil/About/NationalCentersofExpertise/CoastalStormDamageReduction(Planning).aspx

Virginia Institute of Marine Science (VIMS) Center for Coastal Resources Management
ccrm.vims.edu/livingshorelines/index.html

Coasts, Oceans, Ports & Rivers Institute (COPRI)
www.mycopri.org/livingshorelines

The Nature Conservancy
www.nature.org/ourinitiatives/habitats/oceanscoasts/howwework/helping-oceans-adapt-to-climate-change.xml

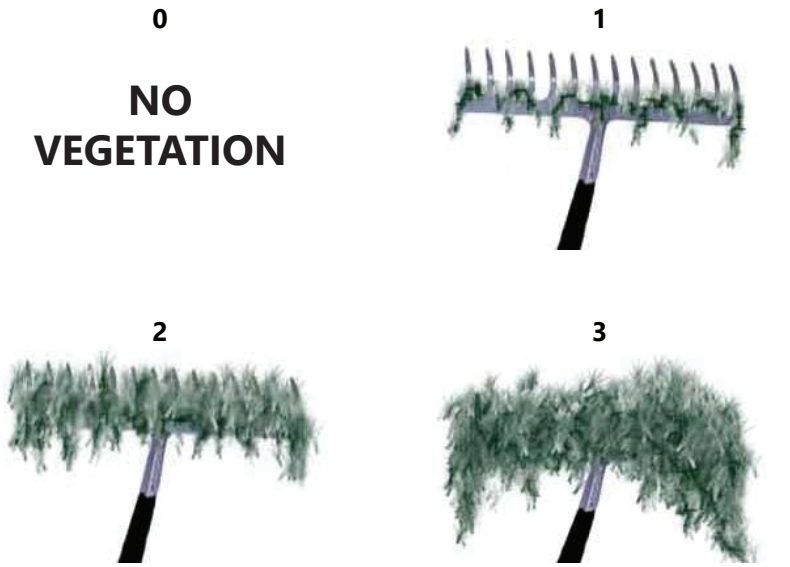
US Army Corps of Engineers®

Developed with support and funding from SAGE, NOAA and USACE; February 2015

7

APPENDIX C
NAGAWICKA LAKE 2016 AQUATIC PLANT SURVEY PLANT SPECIES DISTRIBUTION MAPS

Figure B.1
Rake Fullness Ratings



Source: Wisconsin Department of Natural Resources and SEWRPC

SOURCES OF INFORMATION:

Borman, S., Korth, R., & Temte, J. (2014). Through the Looking Glass: A Field Guide to Aquatic Plants, Second Edition. Stevens Point, WI, USA: Wisconsin Lakes Partnership.

Robert W. Freckman Herbarium: wisplants.uwsp.edu

Skawinski, P. M. (2014). Aquatic Plants of the Upper Midwest: A Photographic Field Guide to Our Underwater Forests, Second Edition. Wausau, Wisconsin, USA: Self-Published.

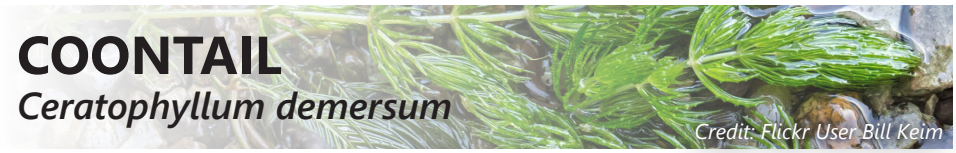
University of Michigan Herbarium: michiganflora.net/home.aspx

UW-System WisFlora. 2016. wisflora.herbarium.wisc.edu/index.php

Native

COONTAIL

Ceratophyllum demersum


Credit: Flickr User Bill Keim

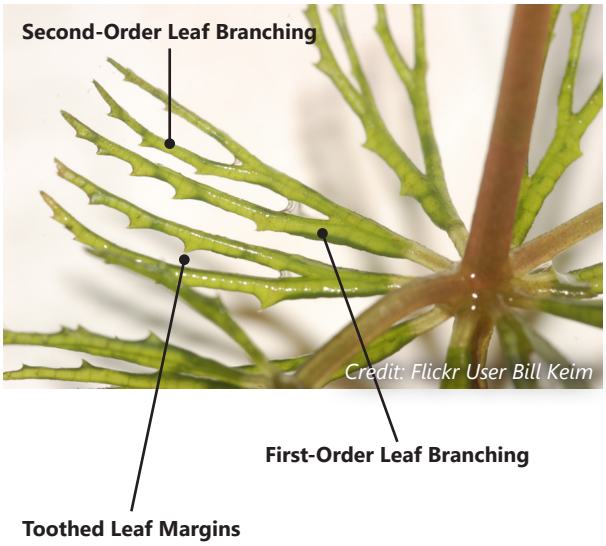
Identifying Features

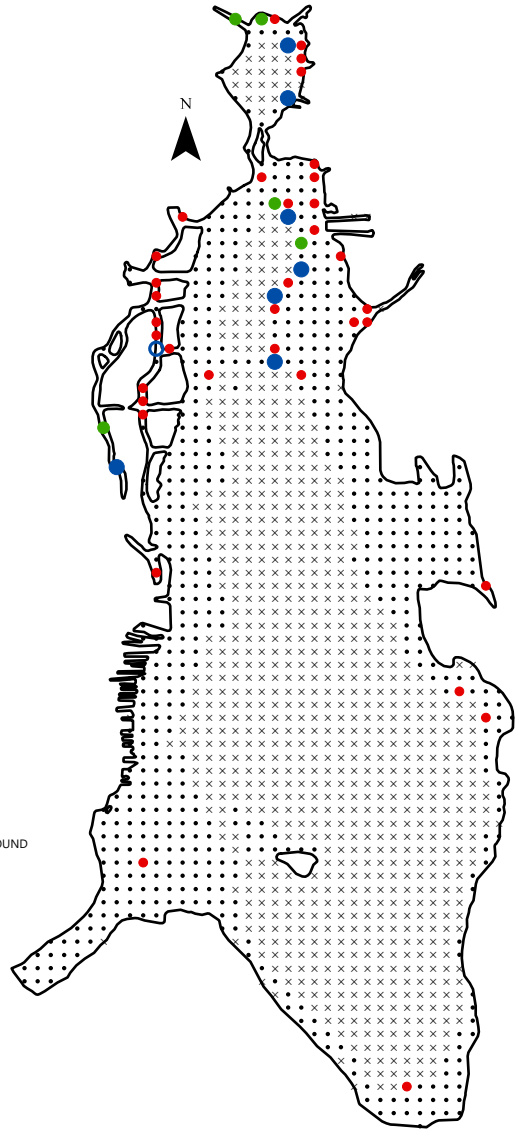
- Often bushy near tips of branches, giving the raccoon tail-like appearance ("coontail")
- Whorled leaves with one to two orders of
- branching and small teeth on their margins
- Flowers (rare) small and produced in leaf axils

Coontail is similar to spiny hornwort (C. echinatum) and muskgrass (Chara spp.), but spiny hornwort has some leaves with three to four orders of branching, and coontail does not produce the distinct garlic-like odor of muskgrass when crushed

Ecology

- Common in lakes and streams, both shallow and deep
- Tolerates poor water quality (high nutrients, chemical pollutants) and disturbed conditions
- Stores energy as oils, which can produce slicks on the water surface when plants decay
- Anchors to the substrate with pale, modified leaves rather than roots
- Eaten by waterfowl, turtles, carp, and muskrat





Native

MUSKGRASSES

Chara spp.


Credit: Flickr User Jeremy Halls

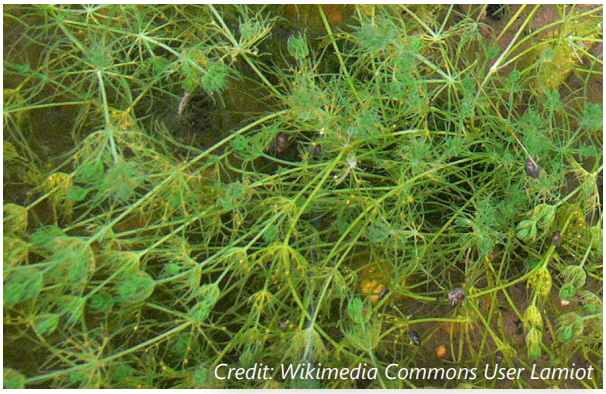
Identifying Features

- Leaf-like, ridged side branches develop in whorls of six or more
- Often encrusted with calcium carbonate, which appears white upon drying (see photo below)
- Yellow reproductive structures develop along the whorled branches in summer
- Emits a garlic-like odor when crushed

Stoneworts (*Nitella* spp.) are similar large algae, but their branches are smooth rather than ridged and more delicate

Ecology

- Found in shallow or deep water over marl or silt, often growing in large colonies in hard water
- Overwinters as rhizoids (cells modified to act as roots) or fragments
- Stabilizes bottom sediments, often among the first species to colonize open areas
- Food for waterfowl and excellent habitat for small fish


Credit: Wikimedia Commons User Lamiot

Native

COMMON WATERWEED

Elodea canadensis

Credit: Flickr User Corey Raimond

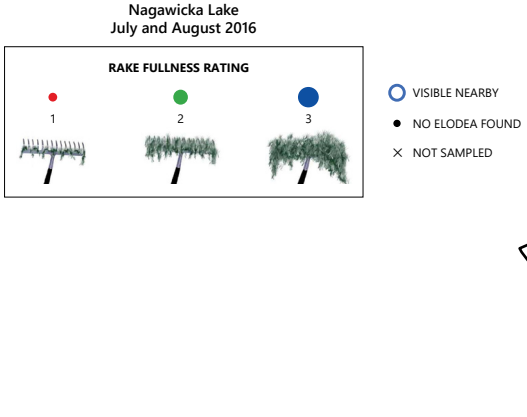
Identifying Features

- Slender stems, occasionally rooting
- Leaves lance-shaped, in whorls of three (rarely two or four), 6.0 to 17 mm long and averaging 2.0 mm wide
- When present, tiny male and female flowers on separate plants (females more common), raised to the surface on thread-like stalks

Ecology

- Found in lakes and streams over soft substrates tolerating pollution, eutrophication and disturbed conditions
- Often overwinters under the ice
- Produces seeds only rarely, spreading primarily via stem fragments
- Provides food for muskrat and waterfowl
- Habitat for fish or invertebrates, although dense stands can obstruct fish movement

Credit: Wikimedia Commons User Christian Fischer



Native

WATER STARGRASS

Heteranthera dubia

Credit: Wikimedia Commons User Fritzflohrreynolds

Identifying Features

- Stems slender, slightly flattened, and branching
- Leaves narrow, alternate, with no stalk, and lacking a prominent midvein
- When produced, flowers conspicuous, yellow, and star-shaped (usually in shallow water) or inconspicuous and hidden in the bases of submersed leaves (in deeper water)

Yellow stargrass may be confused with pondweeds that have narrow leaves, but it is easily distinguished by its lack of a prominent midvein and, when present, yellow blossoms

Ecology

- Found in lakes and streams, shallow and deep
- Tolerates somewhat turbid waters
- Overwinters as perennial rhizomes
- Limited reproduction by seed
- Provides food for waterfowl and habitat for fish

Credit: Flickr User Jill Lee

Native

SMALL, FORKED, AND PERENNIAL DUCKWEED

Lemna spp.


Credit: Wikimedia Commons User Mokkie

Identifying Features

- Free-floating, green, round fronds
- May have several fronds in a cluster, but each frond has only one root
- Small Duckweed (*L. minor*) is smooth and flat on the top
- Forked Duckweed (*L. trisulca*) has pointed fronds, giving it an "oar and rowboat" appearance
- Perennial Duckweed (*L. turionifera*) has a row of small bumps down the middle

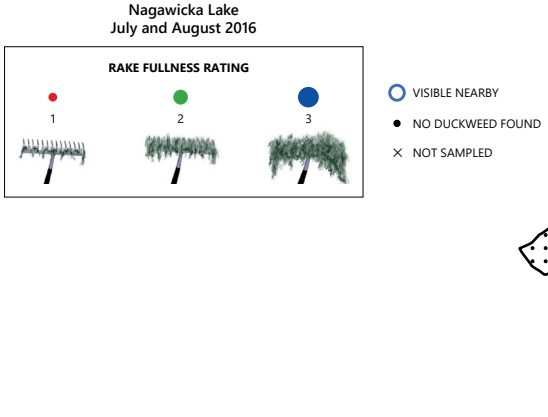
Ecology

- Free-floating duckweed is not dependent on depth, sediment type, or water clarity
- Associated with eutrophic waters

Credit: Flickr User Andreas Rockstein

Credit: Wikimedia Commons User Petr Filippov

Credit: Wikimedia Commons User Stefan.lefnaer



Nonnative/ Exotic

PURPLE LOOSESTRIFE

Lythrum salicaria


Credit: Wikimedia Commons User Liz West

Identifying Features

- Terrestrial or semi-aquatic, emergent forb
- Stems often angled with four, five, or more sides, and growing one to two meters tall
- Flowers deep pink or purple, six-parted, 12 to 25 mm wide, and in groups
- Leaves lance-like, four to 11 cm long and either opposite or in whorls of three

Purple loosestrife, if small, is similar to winged loosestrife (Lythrum alatum), but winged loosestrife differs in having leaves generally smaller (<5.0 cm long), leaves mostly alternate (only lower leaves opposite), and flowers mostly held singly in the leaf axils rather than in pairs or groups

Ecology/Control

- Found in shallows, along shores, and in wet to moist meadows and prairies
- Invasive and continues to escape from ornamental plantings
- Galerucella beetles have been successfully used to control purple loosestrife. Plants may also be dug or pulled when small, but they subsequently should be placed in a landfill or burned. Several herbicides are effective, but application near water may require permits and aquatic-use formulas


Credit: Wikimedia Commons User Liz West


Credit: Paul Skawinski


Credit: Consortium of Wisconsin Herbaria

Native

VARIOUS-LEAVED WATERMILFOIL

Myriophyllum heterophyllum

Credit: Wikimedia Commons User Leslie J. Mehrhoff

Identifying Features

- Very short internodes lead to very bushy appearance
- Leaves in whorls of four to six, with some scattered on stem, divided into seven to 14 pairs of leaflets
- No winter buds are formed
- Flower bracts are larger than flowers and have smooth or slightly serrated edges

Various-leaved watermilfoil is similar to other water milfoils. Eurasian watermilfoil (*M. spicatum*) tends to be less bushy, limp out of water, and produce more leaflets per leaf

Ecology

- Found in lakes and streams, up to 15 feet but mostly shallower
- Plants on wet shorelines may produce deeply serrate "terrestrial" leave or bracts
- Consumed by waterfowl
- Provides habitat for aquatic invertebrates and shade, shelter, and foraging for fish

Credit: Wikimedia Commons User Leslie J. Mehrhoff

Nonnative/ Exotic

EURASIAN WATERMILFOIL

Myriophyllum spicatum

Credit: Paul Skawinski

Identifying Features

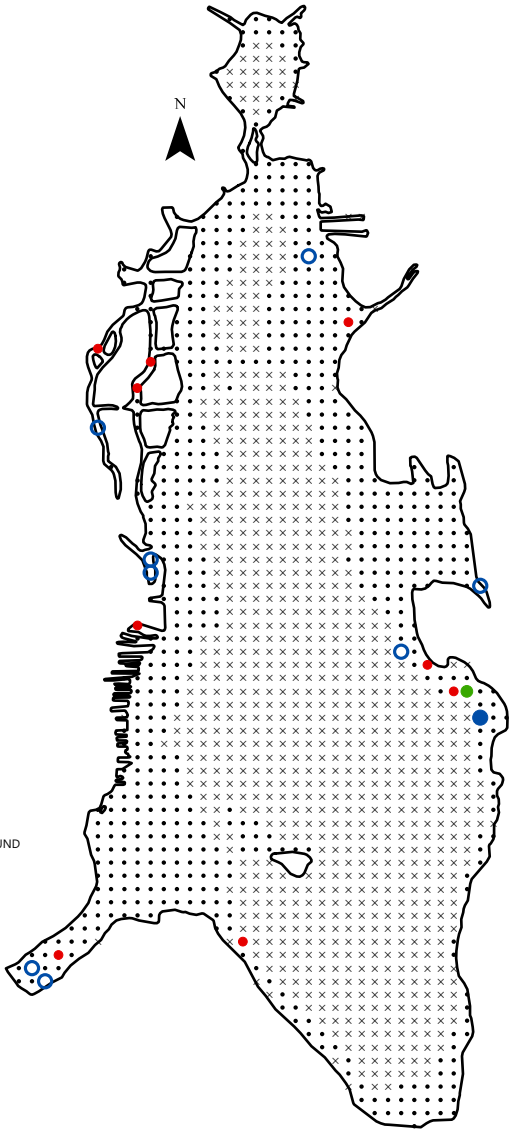
- Stems spaghetti-like, often pinkish, growing long with many branches near the water surface
- Leaves with 12 to 21 pairs of leaflets
- Produces no winter buds (turions)

Eurasian watermilfoil is similar to northern watermilfoil (*M. sibiricum*). However, northern watermilfoil has five to 12 pairs of leaflets per leaf and stouter white or pale brown stems

Credit: Paul Skawinski

Ecology

- Hybridizes with northern (native) watermilfoil, resulting in plants with intermediate characteristics
- Invasive, growing quickly, forming canopies, and getting a head-start in spring due to an ability to grow in cool water
- Grows from root stalks and stem fragments in both lakes and streams, shallow and deep; tolerates disturbed conditions
- Provides some forage to waterfowl, but supports fewer aquatic invertebrates than mixed stands of aquatic vegetation



Native

BUSHY PONDWEED OR SLENDER NAIAD

Najas flexilis

Credit: Flickr User Tab Tannery

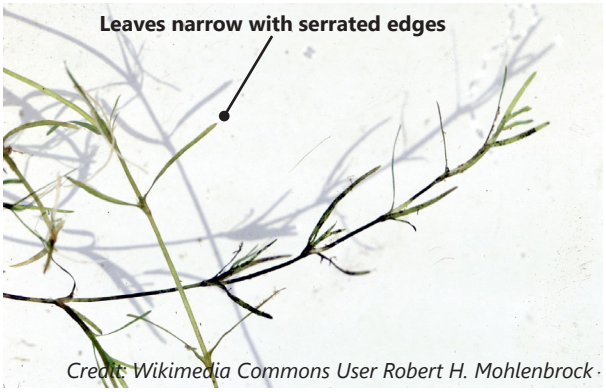
Identifying Features

- Leaves narrow (0.4 to 1.0 mm) and pointed with broader bases where they attach to the stem and finely serrated margins
- Flowers, when present, tiny and located in leaf axils
- Variable size and spacing of leaves, as well as compactness of plant, depending on growing conditions

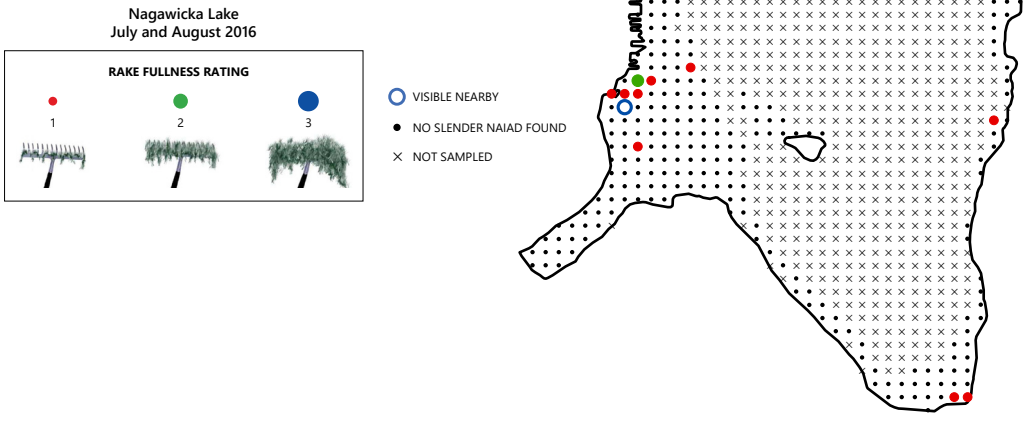
Two other Najas occur in southeastern Wisconsin. Southern naiad (N. guadalupensis) has wider leaves (to 2.0 mm). Spiny naiad (N. marina) has coarsely toothed leaves with spines along the midvein below

Ecology

- In lakes and streams, shallow and deep, often in association with wild celery
- One of the most important forages of waterfowl
- An annual plant that completely dies back in fall and regenerates from seeds each spring; also spreading by stem fragments during the growing season



Credit: Wikimedia Commons User Robert H. Mohlenbrock



Nonnative/ Exotic

SPINY NAIAD

Najas marina

Credit: Wikimedia Commons User Pascale Guinchard

Identifying Features

- Stems stiff and spiny, often branching many times
- Leaves stiff, 1.0 to 4.0 mm thick, with coarse teeth along the margins and midvein on the underside

Spiny naiad is quite distinct from other naiads due to its larger, coarsely toothed leaves and the irregularly pitted surface of its fruits. Spiny naiad is presumably introduced in Wisconsin, but it is considered native in other states, including Minnesota

Ecology

- Alkaline lakes, water quality ranging from good to poor
- An annual, regenerating from seed each year
- Occurs as separate male and female plants
- Capable of growing aggressively

Credit: Wikimedia Commons User Kristian Peters

Native

SPATTERDOCK

Nuphar variegata

Credit: Wikimedia Commons User Cephas

Identifying Features

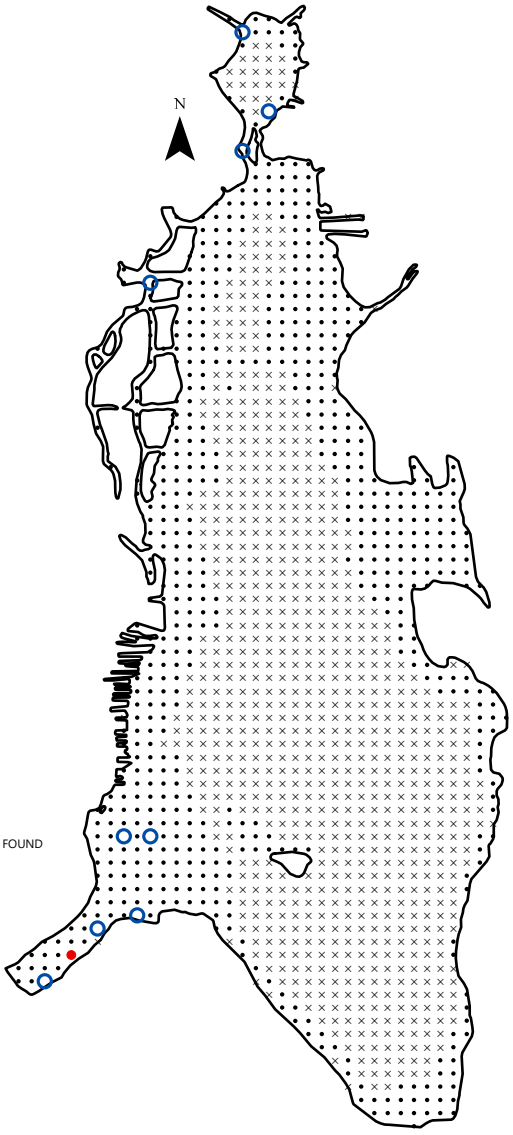
- Leaf stalks winged in cross-section
- Most leaves floating on the water surface, heart-shaped, and notched, with rounded lobes at the base
- Yellow flowers, 2.5 to 5.0 cm wide, often with maroon patches at the bases of the sepals (petal-like structures) when viewed from above

Unlike spatterdock, the similar yellow pond lily (Nuphar advena) has leaf stalks that are not winged in cross-section, leaves that more often emerge above the water surface, and leaf lobes that are more pointed. Spatterdock is superficially similar to water lilies (Nymphea spp.), but it has yellow versus white flowers and leaves somewhat heart-shaped versus round. American lotus (Nelumbo lutea) is also similar, but its leaves are round and un-notched, and its flowers are much larger

Credit: Flickr User Jason Hollinger

Ecology

- In sun or shade and mucky sediments in shallows and along the margins of ponds, lakes, and slow-moving streams
- Overwinters as a perennial rhizome
- Flowers opening during the day, closing at night, and with the odor of fermented fruit
- Buffers shorelines
- Provides food for waterfowl (seeds), deer (leaves and flowers), and muskrat, beaver, and porcupine (rhizomes)
- Habitat for fish and aquatic invertebrates



Native

WHITE WATER LILY

Nymphaea odorata


Credit: Flickr User Ryan Hodnett

Identifying Features

- Leaf stalks round in cross-section with four large air passages
- Floating leaves round (four to 12 inches wide under favorable conditions), *with a notch* from the outside to the center, and reddish-purple underneath
- Flowers white with a yellow center, three to nine inches wide

Pond lilies (*Nuphar* spp.) are superficially similar, but have yellow flowers and leaves somewhat heart-shaped. American lotus (*Nelumbo lutea*) is also similar, but its leaves are unnotched

Ecology

- Found in shallow waters over soft sediments
- Leaves and flowers emerge from rhizomes
- Flowers opening during the day, closing at night
- Seeds consumed by waterfowl, rhizomes consumed by mammals


Credit: Wikimedia Commons User Kurt Stüber

Native/ Exotic

CURLY-LEAF PONDWEED

Potamogeton crispus

Credit: Paul Skawinski

Identifying Features

- Stems slightly flattened and both stem and leaf veins often somewhat pink
- Leaf margins very wavy and finely serrated
- Stipules (3.0 to 8.0 mm long) partially attached to leaf bases, disintegrating early in the season
- Produces pine cone-like overwintering buds (turions)

Curly-leaf pondweed may resemble clasping-leaf pondweed (*P. richardsonii*), but the leaf margins of the latter are not serrated

Credit: Paul Skawinski

Ecology

- Found in lakes and streams, both shallow and deep
- Tolerant of low light and turbidity
- Disperses mainly by turions
- Adapted to cold water, growing under the ice while other plants are dormant, but dying back during mid-summer in warm waters
- Produces winter habitat, but mid-summer die-offs can degrade water quality and cause algal blooms
- Maintaining or improving water quality can help control this species, because it has a competitive advantage over native species when water clarity is poor

Native

FRIES' PONDWEED

Potamogeton friesii

Credit: Flickr User Liam Rooney

Identifying Features

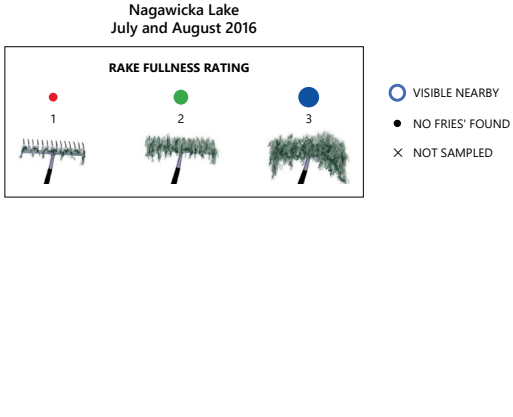
- Slender stems slightly compressed
- Submerged leaves linear with no petiole, one row of lacunar cells on each side of midvein, and 5-7 veins
- Tip of leaf rounded with short bristle
- Winter bud fan shaped and in two planes, with inner leaves at 90 degrees from outer leaves

Fries' pondweed is similar to other narrow-leaved pondweeds such as small pondweed (*P. pusillis*) and stiff pondweed (*P. strictifolius*) but other narrow pondweeds do not create a fan shaped winter bud

Ecology

- Common in calcareous lakes and slow-moving streams
- Overwinters largely as winter buds (turions)
- Provides food for waterfowl,
- Provides habitat for fish and aquatic invertebrates

Credit: Flickr User Brenton Butterfield



Native

VARIABLE PONDWEED

Potamogeton gramineus

Credit: Wikimedia Commons User Tristan He

Identifying Features

- Often heavily branched
- Submerged leaves narrow to lance-shaped, with three to seven veins, smooth margins, without stalks, but the blade tapering to the stem
- Floating leaves with 11 to 19 veins and a slender stalk that is usually longer than the blade
- Often covered with calcium carbonate in hard water

Variable pondweed is similar to Illinois pondweed (*P. illinoensis*), but Illinois pondweed has submerged leaves with nine to 19 veins

Ecology

- Shallow to deep water, often with muskgrass, wild celery, and/or slender naiad; requires more natural areas that receive little disturbance
- Overwinters as rhizomes or winter buds (turions)
- Provides food for waterfowl, muskrat, deer, and beaver
- Provides habitat for fish and aquatic invertebrates

Credit: Flickr User Jason Hollinger

Native

ILLINOIS PONDWEED

Potamogeton illinoensis


Credit: Flickr User Dick Culbert

Identifying Features

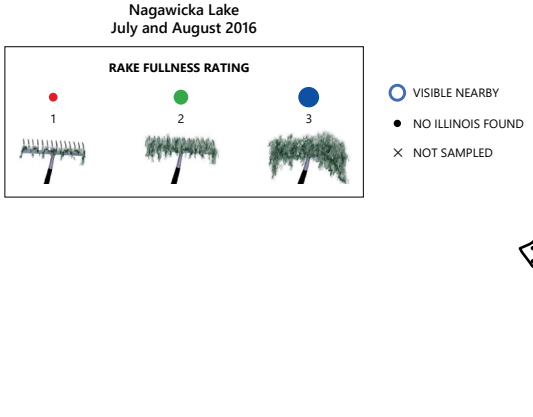
- Stout stems up to 2.0 m long, often branched
- Submerged leaves with nine to 19 veins (midvein prominent) on short stalks (up to 4.0 cm) or attached directly to the stem
- Floating leaves, if produced, elliptical, with 13 to 29 veins
- Often covered with calcium carbonate in hard water

Variable pondweed (*P. gramineus*) is similar to Illinois pondweed, but differs in having three to seven veins on submerged leaves

Ecology

- Lakes with clear water, shallow or deep, neutral or hard, over soft sediments
- Overwinters as rhizomes or remains green under the ice
- Provides food for waterfowl, muskrat, deer, and beaver
- Provides excellent habitat for fish and aquatic invertebrates


Credit: Flickr User Fernando Arcas



Native

FLOATING-LEAF PONDWEED

Potamogeton natans


Credit: Wikimedia Commons User Stefan.lefnaer

Identifying Features

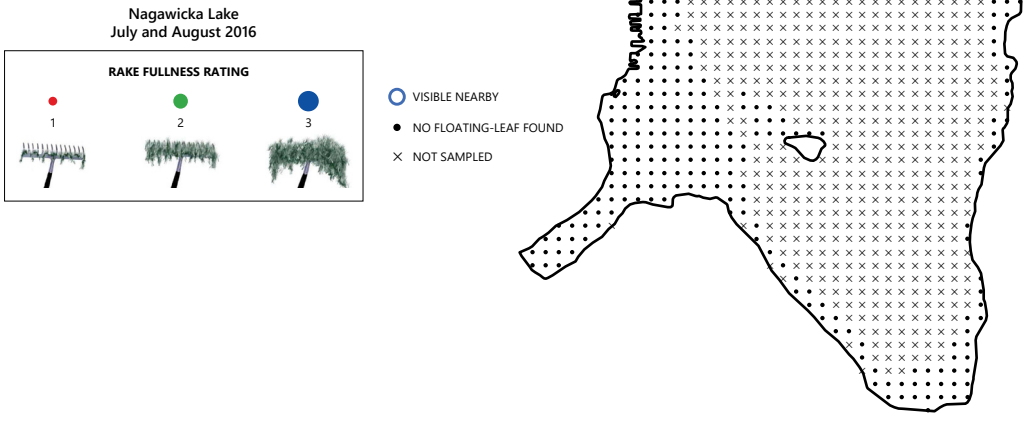
- Floating leaves (5.0 to 10 cm long) with heart-shaped bases and 17 to 37 veins
- Floating leaf stalks bent where they meet the leaf, causing the leaf to be held at roughly a 90-degree angle to the stalk
- Submersed leaves (1.0 to 2.0 mm wide) linear and stalk-like, with three to five veins

Floating-leaf pondweed is similar to Oakes' pondweed (*P. oakesianus*) and spotted pondweed (*P. pulcher*). Oake's pondweed is smaller, with floating leaves 2.5 to 6.0 cm long and submersed leaves 0.25 to 1.0 mm wide. Spotted pondweed differs in having small black spots on its stems and leaf stalks and lance-shaped submersed leaves with wavy margins


Credit: Wikimedia Commons User Stefan.lefnaer

Ecology

- Usually in shallow waters (<2.5 m) over soft sediment
- Emerges in spring from buds formed along rhizomes
- Provides food for waterfowl, muskrat, beaver, and deer
- Holds fruit on stalks until late in the growing season, which provides valuable feeding opportunities for waterfowl
- Provides good fish habitat



Native

WHITE-STEM PONDWEED

Potamogeton praelongus


Credit: Flickr User Bas Kers

Identifying Features

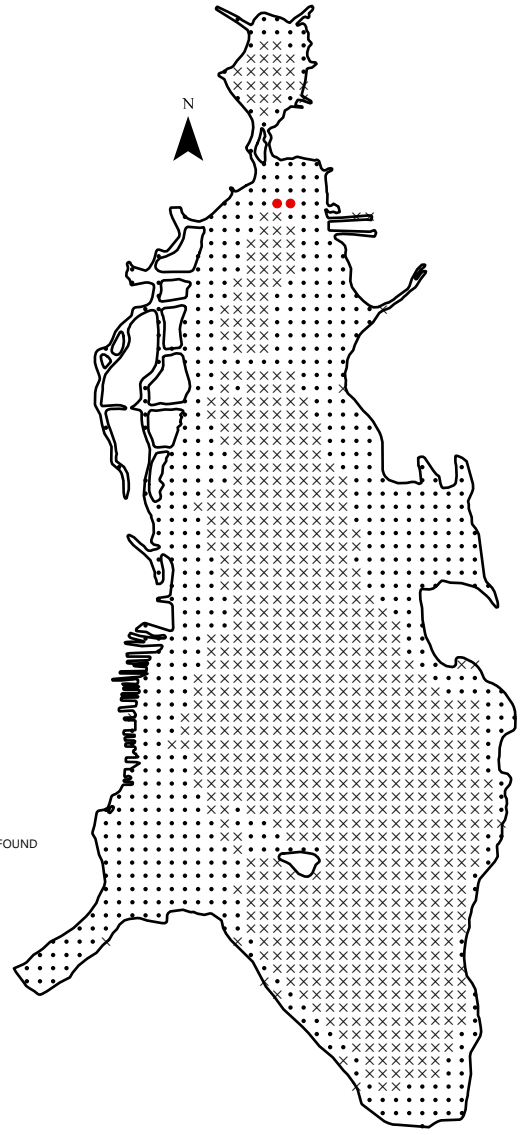
- Stems usually pale and zig-zagging
- Leaves clasping, alternate, with three to five prominent veins and 11 to 35 smaller ones, with boat-shaped tips that often split when pressed between fingers

White-stem pondweed is similar to clasping pondweed (*P. richardsonii*), but the leaves of clasping pondweed do not have boat-shaped tips that split when pressed

Ecology

- Found in clear lakes in water three to 12 feet deep over soft sediments
- "Indicator species" due to its sensitivity to water quality changes; its disappearance indicating degradation; requires more natural areas that receive little disturbance
- Sometimes remains evergreen beneath the ice
- Provides food for waterfowl, muskrat, beaver, and deer
- Provides habitat for trout and muskellunge


Credit: Flickr User fabelfroh



Native

CLASPING-LEAF PONDWEED

Potamogeton richardsonii

Credit: Flickr User Bas Kers

Identifying Features

- Leaves alternating along and clasping the stem, with wavy edges, coming to a point at the tip, and often with three to five veins prominent among many more that are faintly visible
- Produces no floating leaves

Clasping pondweed is similar to white-stem pondweed (*P. praelongus*), but the latter has boat-shaped leaf tips that split when pressed between one's fingers. The exotic curly-leaf pondweed (*P. crispus*) may appear similar, but differs by having serrated leaf margins

Ecology

- In lakes and streams, shallow and deep, often in association with coontail
- Tolerant of disturbance
- Fruits a food source for waterfowl and plants browsed by muskrat, beaver, and deer
- Stems emerging from perennial rhizomes

Credit: Paul Skawinski

Native

STIFF PONDWEED

Potamogeton strictifolius

Credit: Donald Cameron

Identifying Features

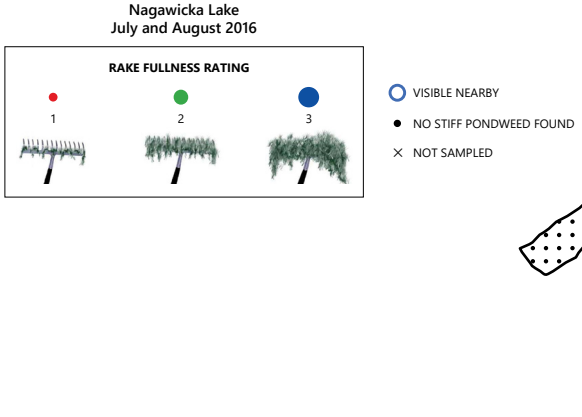
- Stems slender and flattened
- Leaves 2-6 cm long, with 3-5 veins, usually with paired glands at their bases, and sharply pointed or tipped with a fine bristle
- Stipule white, free from leaves, 7-15 mm and becoming fibrous by midsummer
- Fruits round, without ridges, and 2-3 mm long

Stiff pondweed is similar to small pondweed (*P. pusillus*), but it differs in having glands at the bases of its leaves, flattened stems, and stipules that are not free from the stems.

Ecology

- Found in lakes, shallow and deep
- Produces overwintering buds known as turions
- Relatively uncommon in southeastern Wisconsin

Credit: Flickr User Brenton Butterfield



Native

FLAT-STEM PONDWEED

Potamogeton zosteriformis


Credit: Donald Cameron

Identifying Features

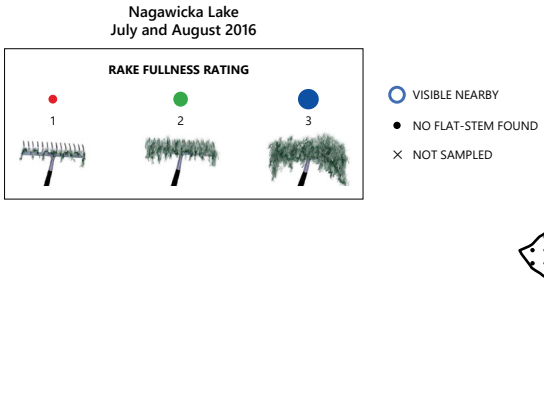
- Stems strongly flattened
- Leaves up to four to eight inches long, pointed, with a prominent midvein and many finer, parallel veins
- Stiff winter buds consisting of tightly packed ascending leaves

Flat-stem pondweed may be confused with yellow stargrass (*Heteranthera dubia*), but the leaves of yellow stargrass lack a prominent midvein.

Ecology

- Found at a variety of depths over soft sediment in lakes and streams
- Overwinters as rhizomes and winter buds
- Has antimicrobial properties
- Provides food for waterfowl, muskrat, beaver, and deer
- Provides cover for fish and aquatic invertebrates


Credit: Donald Cameron



Native

WHITE WATER CROWFOOT

Ranunculus aquatilis

Credit: Wikimedia Commons User Hans Hillewaert

Identifying Features

- Submersed leaves finely divided into thread-like sections, and arranged alternately along the stem
- Flowers white, with five petals
- May or may not produce floating leaves

White water crowfoot is similar to other aquatic *Ranunculus* spp. However, the latter have yellow flowers and leaf divisions that are flat, rather than thread-like.

Ecology

- Shallow water in lakes or streams, often with high alkalinity
- Often forms dense patches near springs or sand bars
- Emerges from rhizomes in the spring
- Fruit and foliage consumed by waterfowl and upland birds alike
- Habitat for invertebrates that are food for fish like trout

Credit: Wikimedia Commons User Chmee2

Native

LARGE DUCKWEED

Spirodela polyrrhiza

Credit: Flickr User gailhampshire

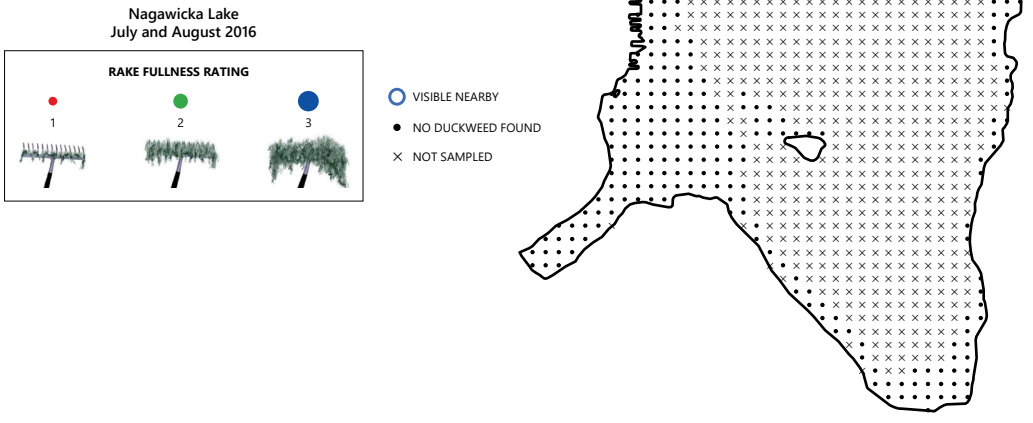
Identifying Features

- Free-floating, nearly cicular fronds with 5 – 15 veins
- Often has several fronds in a cluster, with multiple roots
- Typically green above and a reddish-purple beneath

Ecology

- Found throughout Wisconsin
- Often found with duckweed species
- Not dependent on depth, sediment type, or water clarity
- Requires adequate nutrients in the water to sustain growth

Credit: Wikimedia Commons User Stefan.lefnaer



Native

SAGO PONDWEED

Stuckenia pectinata


Credit: Flickr User Christian Fischer

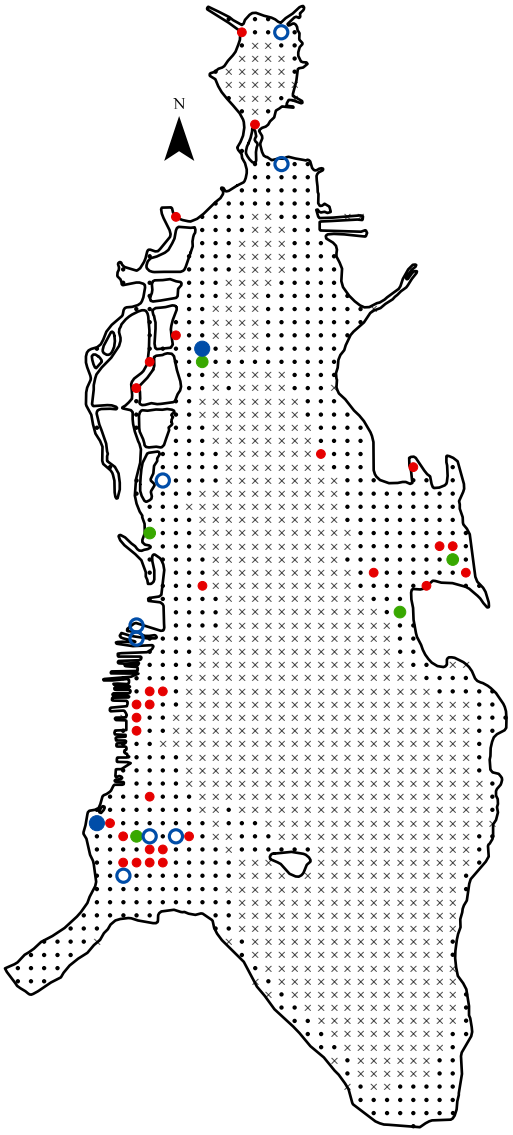
Identifying Features

- Stems often *slightly zig-zagged* and forked multiple times, yielding a fan-like form
- Leaves one to four inches long, very thin, and ending in a sharp point
- Whorls of fruits spaced along the stem may appear as beads on a string

Ecology

- Lakes and streams
- Overwinters as rhizomes and starchy tubers
- Tolerates murky water and disturbed conditions
- Provides abundant fruits and tubers, which are an *important food for waterfowl*
- Provides habitat for juvenile fish


Credit: Flickr User Christian Fischer



Native

BLADDERWORTS

Utricularia spp.


Credit: Paul Skawinski

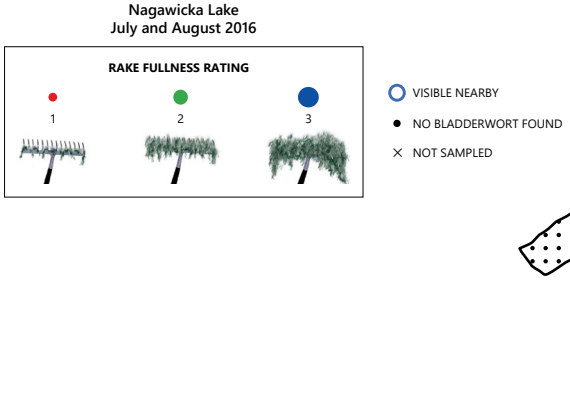
Identifying Features

- Flowers snapdragon-like, yellow or purple, held on stalks above the water surface
- *Producing bladders* (small air chambers on the stem) that capture prey and give buoyancy to the stem
- Stems either floating (due to air bladders) or anchored in the substrate; branches finely divided, if floating

Several similar bladderworts occur in southeastern Wisconsin

Ecology

- Most species found in quiet shallows and along shores, but common bladderwort (*Utricularia vulgaris*) sometimes occurring in water several feet deep
- Provides forage and cover for a wide range of aquatic organisms
- Bladders capture and digest prey, including small invertebrates and protozoans



Native

WATER CELERY OR EELGRASS

Vallisneria americana

Credit: Wikimedia Commons User Fredlyfish4

Identifying Features

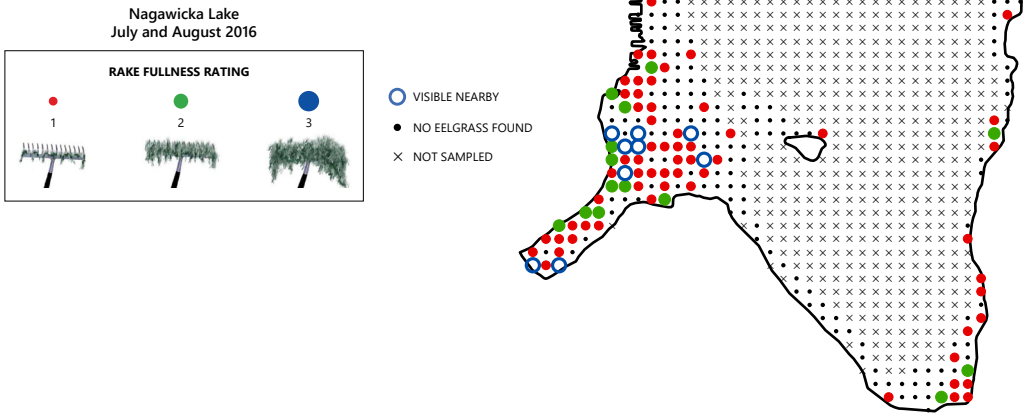
- Leaves ribbon-like, up to two meters long, with a prominent stripe down the middle, and emerging in clusters along creeping rhizomes
- Male and female flowers on separate plants, female flowers raised to the surface on spiral-coiled stalks

The foliage of eelgrass could be confused with the submersed leaves of bur-reeds (*Sparganium* spp.) or arrowheads (*Sagittaria* spp.), but the leaves of eelgrass are distinguished by their prominent middle stripe. The leaves of ribbon-leaf pondweed (*Potamogeton epihydrus*) are also similar to those of eelgrass, but the leaves of the former are alternately arranged along a stem rather than arising from the plant base

Credit: Wikimedia Commons User Fredlyfish4

Ecology

- Firm substrates, shallow or deep, in lakes and streams
- Spreads by seed, by creeping rhizomes, and by offsets that break off and float to new locations in the fall
- All portions of the plant consumed by waterfowl; an especially important food source for Canvasback ducks
- Provides habitat for invertebrates and fish



Native

COMMON, NORTHERN, AND BRAZILIAN WATERMEAL

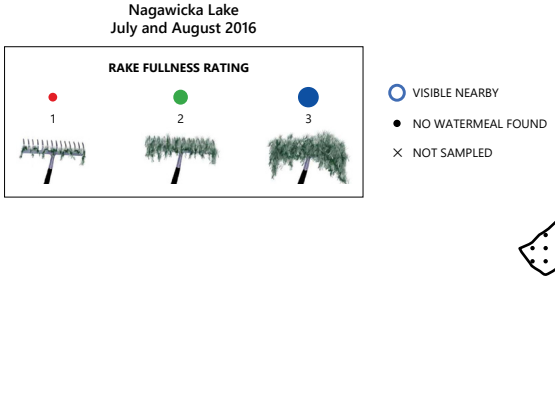
***Wolffia* spp.**

Identifying Features

- Free-floating, green plant without roots, stems, or leaves, spherical or oblong
- Individual plants hardly larger than a pinhead
- Common Watermeal (*W. columbiana*) pale green, asymmetrical globes
- Northern Watermeal (*W. borealis*) flattened, ellipsoid, and dotted, with a pointed apex
- Brazilian Watermeal (*W. brasiliensis*) dotted, ellipsoid, with a rounded apex

Ecology

- Found throughout Wisconsin, except northern lakes and forest ecoregion
- Often found with duckweed species
- Not dependent on depth, sediment type, or water clarity
- Requires adequate nutrients in the water to sustain growth



NAGAWICKA LAKE WDNR SENSITIVE AREAS REPORT

APPENDIX D

LKS 0428.000

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

AQUATIC PLANT MANAGEMENT

SENSITIVE AREA ASSESSMENT SUMMARY

File Ref:

LAKE: NAGAWICKA COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #1

The area is commonly known as St. John's Bay. This area's most important function is that of spawning habitat for northern pike. The Department Fish Manager has determined through creel census that the northern pike population in the lake is diminishing, so it is important to protect and enhance northern's natural spawning habitat. St. John's Bay is the primary northern spawning area on the lake. The vegetation here is not very diverse but does provide nursery and feeding habitat year round for bass and panfish, as well as the northerns. It is important to end chemical treatments of this area by July 1 so that there will be sufficient regrowth of vegetation by spring for the northerns.

The banks in St. John's Bay provide muskrat with shelter. Raccoons, geese and mallards feed and rear their young in this area. The area just west of the island is primarily sand and gravel bottom and is a popular swimming area.

Vegetation in St. John's Bay helps stabilize the soft sediments. The plants also support an abundant amount of larger sized invertebrates. St. John's Bay also acts as a nutrient and sediment trap for the lake.

MANAGEMENT RECOMMENDATIONS FOR AREA #1

1. Mechanical treatment allowed with restrictions: Harvesting should end by July 1st and should be restricted to channels 25 feet from piers and extending out into open water. Minimal hand control allowed around piers & beaches.

2. Chemical treatment for Eurasian milfoil and purple loosestrife allowed only in navigational channels before July 1st.

3. None of the following inlake activities allowed:
   a. dredging
   b. filling
   c. boardwalks
   d. mechanical harvesting of vegetation in the area located northeast of St. John's Bay.

4. The following activities allowed with conditions:
   a. pea gravel/sand blankets in compliance with DNR provisions.
   b. aquascreen limited to area inside of navigational channel.

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

File Ref:

AQUATIC PLANT MANAGEMENT

SENSITIVE AREA ASSESSMENT SUMMARY

LAKE: NAGAWICKA COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #2

This area of Nagawicka Lake has an unusually large amount of shoreline, and is therefore extremely valuable to fish and wildlife. The shoreline gravel provides spawning beds for bass and is heavily used by bluegills. The area is also an important spawning area for northern pike. The vegetation is fairly diverse and includes pondweeds, Yellow & White Water Lilies, Milfoil, Chara, sedges and Arrow Head. This vegetation is not only an excellent habitat, but also provides a food base. The vegetation and stumps, deadfalls, and other woody vegetation are important nursery and feeding areas for fish.

The songbirds, shorebirds and waterfowl use the area for feeding, rearing their young, and nesting. Use during migration is especially high. Muskrat and raccoon also feed and rear their young here.

This area acts as a nutrient and sediment trap for the lake and the aquatic vegetation helps prevent shoreline erosion. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian milfoil.

MANAGEMENT RECOMMENDATIONS FOR AREA #2

1. Chemical treatment not allowed.

2. Mechanical treatment restricted to center of channels.

3. None of the following inlake activities allowed:
   a. filling
   b. pea gravel/sand blanket

4. The following activities allowed with conditions:
   a. dredging restricted to 25 ft center of channel.
   b. private piers for riparians' use only.
   c. boardwalks allowed for educational purposes only.

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

AQUATIC PLANT MANAGEMENT

Carroll D. Besadny
Secretary

SENSITIVE AREA ASSESSMENT SUMMARY

LAKE: NAGAWICKA COUNTY: File Ref: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #3

This area is called "the kettle" and is at the extreme north end of Nagawicka. The water depth drops off very quickly here to over 40 feet. Vegetation in this area includes Tamarack, sedges, cattails, pondweeds, water lilies, Purple Loosestrife and a variety of other emergent wetland vegetation.

The sedge and cattail fringe area is a good northern spawning area. The interconnecting channel between this area and the lake contains substantial amounts of tree stumps which provide cover, as well as a feeding and nursery area for bass and bluegill. The vegetation and substrate in the kettle provides nursery habitat, spawning beds, and feeding areas for bass, bluegill, crappie and northerns.

The kettle is used during migration by shorebirds, songbirds and waterfowl. Muskrat, opossum and raccoon feed and rear their young here. Wading birds feed in the area from spring until late fall.

The kettle acts as a nutrient and sediment trap for the lake and the aquatic vegetation helps prevent shoreline erosion. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian milfoil.

MANAGEMENT RECOMMENDATIONS FOR AREA #3

1. Chemical treatment not allowed.

2. Mechanical treatment restricted to the existing NE channel to provide access to the kettle

3. None of the following inlake activities allowed:
   a. dredging, including stumps and vegetation
   b. pea gravel/sand blanket
   c. aquascreen
   d. filling

4. The following activities allowed with conditions:
   a. private piers for riparians' use only.
   b. boardwalks for educational purposes.

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AQUATIC PLANT MANAGEMENT

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SENSITIVE AREA ASSESSMENT SUMMARY

LAKE: NAGAWICKA COUNTY: File Ref: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #4

The wetland area, also known as Charlie's pond, is regulated by the Army Corp of Engineers, the City of Delafield, and the Department of Natural Resources. This is an extremely valuable wetland complex which drains the south end of Nagawicka Lake. The wetland acts as a sediment and nutrient trap and the aquatic vegetation helps prevent shoreline erosion.

Although the water is rather shallow most of the year, the wetland maintains a small population of most fish species that are found in Nagawicka Lake. The Department's Fish Manager uses the excellent spawning habitat in the wetland to propagate northern pike. The area is also a very good nursery area for most pan fish.

The wetland is considered a quality feeding area for wading birds, especially during migration. Migrating song birds frequent the area to nest, feed and rear their young. Muskrats, raccoons and waterfowl also frequent the area. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian milfoil.

MANAGEMENT RECOMMENDATIONS FOR AREA #4

1. Chemical treatment not allowed.

2. Mechanical treatment limited to minimal hand control by piers.

3. None of the following inlake activities allowed:
   a. dredging
   b. pea gravel/sand blanket
   c. filling

4. The following activities allowed with conditions:
   a. aquascreen can be used, but only on riparians immediate shoreline-remove annually.
   b. piers for riparians' use only.
   c. boardwalks for educational and aesthetic purposes only, and not to provide boat access.

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
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AQUATIC PLANT MANAGEMENT

SENSITIVE AREA ASSESSMENT SUMMARY File Ref:

LAKE: NAGAWICKA COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #5

This area is the Bark River area leading into Nagawicka Lake. It provides an estuary habitat that is used by northerns and a variety of wildlife. The river provides white suckers with very good gravel areas which are used for spawning.

The river supports a variety of plant species. Emergent plants include cattails, sedges, Purple Loosestrife. Submergent plants include milfoil, pondweeds, and Yellow Water Lily.

Waterfowl nest and feed in the area, and it provides excellent habitat during migration. Muskrat and raccoon feed in the area.

This river acts as a nutrient and sediment trap for the lake and the aquatic vegetation helps prevent shoreline erosion. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian Milfoil.

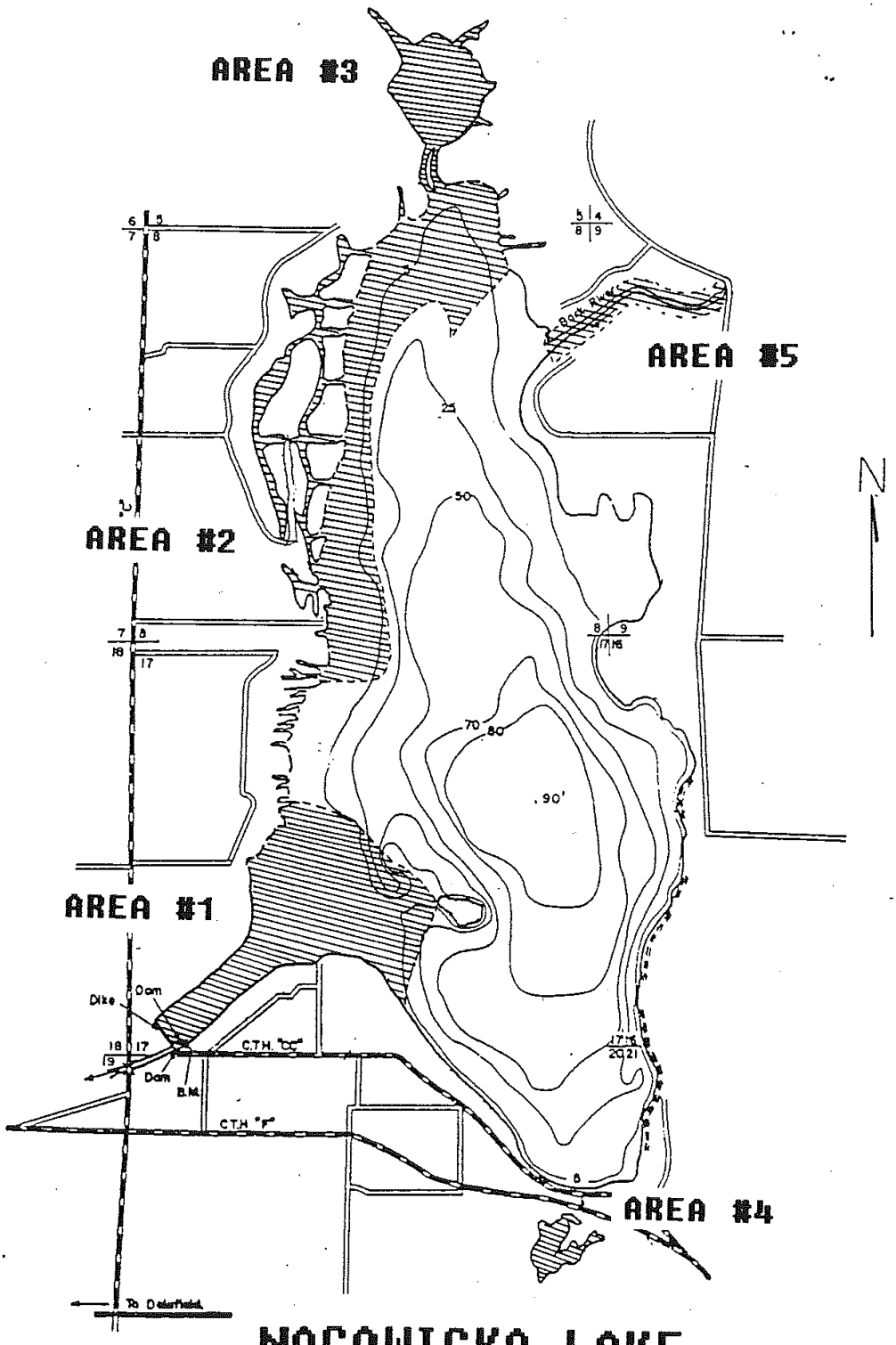
MANAGEMENT RECOMMENDATIONS FOR AREA #5

1. Chemical treatment not allowed.

2. Mechanical treatment limited to hand control for navigation.

3. None of the following inlake activities allowed:
   a. dredging
   b. pea gravel/sand blanket
   c. aquascreen
   d. boardwalks

4. The following activities allowed with conditions:
   a. private piers for riparians' use only.



NAGAWICKA LAKE
SENSITIVE AREAS