Identification of Backwater Nursery Habitats of Colorado Pikeminnow in the Middle Green River, Utah, Using High-Resolution Remotely Sensed Imagery

Environmental Science Division
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NOTATION

bw	backwater
cfs	cubic feet per second; 1 cfs = 0.028317 m ³ /s
GCPs	ground control points
km	kilometer(s)
m	meter(s)
m ²	square meter(s)
NAIP	National Agriculture Imagery Program
RMSE	root mean squared error
SPOT	Satellite Pour l'Observation de la Terre
USGS	U.S. Geological Survey

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IDENTIFICATION OF BACKWATER NURSERY HABITATS OF COLORADO PIKEMINNOW USING HIGH RESOLUTION REMOTELY SENSED IMAGERY

Prepared by

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1 INTRODUCTION

Low-velocity channel-margin habitats serve as important nursery habitats for the endangered Colorado pikeminnow (*Ptychocheilus lucius*) in the middle Green River between Jensen and Ouray, Utah. These habitats, known as backwaters, are associated with emergent sand bars, and are shaped and reformed annually by peak flows. A recent synthesis of information on backwater characteristics and the factors that influence inter-annual variability in those backwaters (Grippio et al. 2015) evaluated detailed survey information collected annually since 2003 on a relatively small sample of backwaters, as well as reach-wide evaluations of backwater surface area from aerial and satellite imagery. The material presented in this report is intended to provide documentation of the specific approach we used to collect, process, and analyze data from remotely sensed imagery of the middle Green River between the U.S. Geological Survey Jensen and Ouray gages, as well as images of the river reach, delineated backwater areas, and the calculated surface area of each.

2 METHODS

Reach-wide backwater mapping consisted of five steps: (1) image registration, (2) enhancement of image display, (3) delineation of backwater features based on image interpretation, (4) evaluation of backwater features, and (5) summary of backwater information. These steps were performed for the 2004 and 2006 National Agriculture Imagery Program (NAIP) images and the 2013 Satellite Pour l'Observation de la Terre (SPOT) image separately.

2.1 IMAGE SPECIFICATION

Two image types were used for mapping backwater features: the NAIP aerial imagery and SPOT 6 multispectral satellite imagery (Table 1). The NAIP seamless image mosaics used for this study consist of image frames collected on August 30, 2004 and July 14, 2006 over our study reach.

TABLE 1 Specification of Remotely Sensed Images

Name	Type	Spatial Resolution	Spectral Band	Acquisition Date
National Agriculture Imagery Program (NAIP)	aerial	1 m	Blue, green, red	August 30, 2004
Satellite Pour l'observation de la Terre (SPOT) 6	satellite	6 m	Blue, green, red, near infrared	July 14, 2006
		1.5 m	Panchromatic	September 18, 2013

The images consist of the blue, green, and red spectral bands and have 1 m spatial resolution. The SPOT image was collected on September 18, 2013, and consists of the blue, green, red, and near infrared (NIR) spectral bands with the panchromatic band. The blue, green, red, and NIR bands have 6 m resolution, and the panchromatic band has 1.5 m resolution. To generate a high resolution (1.5-m) multispectral image, a pansharpening technique was applied to the 6-m SPOT multispectral image and the 1.5-m panchromatic image using ERDAS Imagine software (<http://www.hexagongeospatial.com/products/producer-suite/erdas-imagine>). The resulted pansharpened 1.5-m multispectral image was used to delineate backwater features instead of the original 6-m resolution image.

2.2 REGISTERING IMAGES

In order to match all images in a common projection and coordinate system, the 2004 NAIP image and the 2013 pansharpend SPOT image were registered to the 2006 NAIP image, which is the most interpretable for delineating backwater features of the three images. The registration process was performed using 500+ ground control points (GCPs). The GCPs were automatically generated in the ERDAS Imagine Autosync workstation (<http://www.imagem.nl/en/products/expansion-pack/imagine-autosync>) based on the similarity in pixel values at a given location and its surroundings between the reference (i.e., the 2016 NAIP image) and a subject image (i.e., the 2004 NAIP or 2013 SPOT image). The automatically generated GCPs were interactively adjusted to correct positional errors and improved spatial alignment between the two images. Based on the adjusted GCPs, the subject image was transformed to spatially match the reference image (i.e., the 2006 NAIP image) using a nearest neighbor resampling technique. This technique was selected over more complex techniques in order to preserve the integrity of the original data values. The image registration was performed separately on the 2004 NAIP image and the 2013 pansharpened SPOT image. Through this process, positional accuracy (or spatial alignment) of the 2004 NAIP and pansharpened SPOT images was improve to a sub-pixel level (RMSE < 0.8 pixel).

2.3 ENHANCING IMAGE DISPLAY

Backwater features were manually delineated by interpreting the 2004 and 2006 NAIP images (1 m resolution) and the 2013 pansharpened SPOT image (1.5 m resolution) separately

using the edit tool in the ESRI ArcGIS software (<https://www.arcgis.com/features>). The image was displayed in color on the ArcGIS Desktop one year at a time. When backwater features and their boundaries were not easily identifiable using the default display settings, the display settings were adjusted by applying different color stretch options (e.g., minimum-maximum, histogram equalization, and standard deviation stretches) for the image. The adjustment helps enhancing the interpretability of the image by allocating a larger tonal range to a specific brightness range of the image where features of interest are present (i.e., shallow water, water-sandbar boundaries) in exchange for leaving a smaller tonal range for irrelevant brightness range for non-target features (e.g., vegetation, roads, mountains). The image display settings were interactively adjusted until the interpretability of the image became satisfactory for accurately delineating backwater features in the image.

2.4 IDENTIFYING BACKWATERS BASED ON IMAGE INTERPRETATION

For our analysis, a backwater feature was defined as a habitat having one connection to the mainstem of the river and whose long axis was greater than the width of the mouth including features with the mouth facing either upstream or downstream (Grippio et al. 2017). No minimum size for backwater features was established to be consistent with the approach used by Pucherelli and Clark (1989). By applying these criteria, backwater features were delineated using the following procedure.

Once the image display settings were optimized, an analyst zoomed to one of the backwater features in the image using a zoom-in tool. The analyst visually interpreted the hue, saturation, and intensity of the image and delineated an outline of the backwater feature. The image was further zoomed in when detailed backwater boundaries needed to be delineated but zoomed out when contextual information (e.g., overall color of water of the river) was needed to determine water-nonwater boundaries. When backwater boundaries were obscured by shadow, alternative images that did not cast shadow in the target area were examined using Google Earth (<https://www.google.com/earth>) in order to accurately delineate backwater boundaries. After delineation of a backwater feature was completed, the analyst zoomed out to evaluate its overall consistency with surrounding backwater features, and then moved the image to the next backwater feature using a pan tool. These steps were repeated until all backwater features were delineated.

2.5 EVALUATING BACKWATERS

After all backwater features across the reach were delineated in the image, the accuracy of the backwater delineation was evaluated based on the majority rule. Two analysts who did not engage the initial interpretation and delineation process participated in evaluation. When at least two analysts determined a polygon represented a backwater, then the polygon was included in the final backwater habitat map.

2.6 ORGANIZING AND SUMMARIZING BACKWATER INFORMATION

When the backwater habitat map was finalized, the backwater polygons were labeled based on the following naming convention: backwater, year, and number presented in order from upstream to downstream. For example, the third backwater habitat downstream from the Jensen gage in the 2006 image was noted as bw2006-003. The date of image collection, mean discharge (cfs), coordinates (decimal degree), and surface area (m²) were recorded or computed and organized in an Excel spreadsheet.

3 RESULTS

Figures 1-3 shows the location of backwaters in the study reach. Tables 2-4 present the data for individual backwaters in 2004, 2006, and 2013. These data are analyzed in context with previous reports of backwater surface area in Grippo et al. (2015) to determine trends in backwater number and size from 1987 through 2013. The appendix provides the images of delineated backwaters within 40 subreaches of the study area in each of the study years. High-resolution versions of these images are available for download from the authors upon request.

4 REFERENCES

Grippo, M., LaGory, K.E., Waterman, D., Hayse, J.W., Walston, L.J., Weber, C.C., Magnuson, A.K., and Jiang, X.H. (2017). *Relationships between Flow and the Physical Characteristics of Colorado Pikeminnow Backwater Nursery Habitat in the Middle Green River, Utah.*, Final report to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado, U.S. Fish and Wildlife Service, Denver, Colorado.

Pucherelli, M.J. and Clark, R.C. (1989). "Comprehensive Report (1986-1988) on the Effects of Green River Flows on Backwater Habitat Availability as Determined by Remote Sensing Techniques (Remote Sensing)," *Applied Sciences Referral Memorandum* No. AP-89-4-5.

FIGURE 1 Location of Individual Backwaters in the Middle Green River Study Area in August 2004

FIGURE 2 Location of Individual Backwaters in the Middle Green River Study Area in August 2006

FIGURE 3 Location of Individual Backwaters in the Middle Green River Study Area in August 2013

TABLE 2 Delineated Backwater Characteristics in 2004

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2004-001	8/30/2004	1,220	-109.244530	40.406047	113
bw2004-002	8/30/2004	1,220	-109.253696	40.417221	225
bw2004-003	8/30/2004	1,220	-109.253986	40.418231	200
bw2004-004	8/30/2004	1,220	-109.271544	40.409269	15
bw2004-005	8/30/2004	1,220	-109.271283	40.407376	101
bw2004-006	8/30/2004	1,220	-109.286137	40.398887	91
bw2004-007	8/30/2004	1,220	-109.297653	40.428014	841
bw2004-008	8/30/2004	1,220	-109.328978	40.408565	406
bw2004-009	8/30/2004	1,220	-109.332472	40.397010	2,391
bw2004-010	8/30/2004	1,220	-109.331211	40.392577	839
bw2004-011	8/30/2004	1,220	-109.325445	40.390273	3,547
bw2004-012	8/30/2004	1,220	-109.333160	40.370782	900
bw2004-013	8/30/2004	1,220	-109.333993	40.369131	1,110
bw2004-014	8/30/2004	1,220	-109.336767	40.362346	52
bw2004-015	8/30/2004	1,220	-109.342546	40.358161	243
bw2004-016	8/30/2004	1,220	-109.344058	40.355941	490
bw2004-017	8/30/2004	1,220	-109.363255	40.343182	5,524
bw2004-018	8/30/2004	1,220	-109.362901	40.338727	270
bw2004-019	8/30/2004	1,220	-109.357137	40.334923	222
bw2004-020	8/30/2004	1,220	-109.358115	40.329811	1,272
bw2004-021	8/30/2004	1,220	-109.378408	40.325900	1,086
bw2004-022	8/30/2004	1,220	-109.387633	40.323479	2,003
bw2004-023	8/30/2004	1,220	-109.386212	40.321587	162
bw2004-024	8/30/2004	1,220	-109.390752	40.318486	3,153
bw2004-025	8/30/2004	1,220	-109.398260	40.315127	1,164
bw2004-026	8/30/2004	1,220	-109.399044	40.314755	1,315
bw2004-027	8/30/2004	1,220	-109.402419	40.309086	91
bw2004-028	8/30/2004	1,220	-109.405955	40.305611	2,417
bw2004-029	8/30/2004	1,220	-109.406455	40.304123	35
bw2004-030	8/30/2004	1,220	-109.410165	40.302620	402
bw2004-031	8/30/2004	1,220	-109.408591	40.300679	607
bw2004-032	8/30/2004	1,220	-109.408504	40.299953	290
bw2004-033	8/30/2004	1,220	-109.409777	40.298055	374
bw2004-034	8/30/2004	1,220	-109.410087	40.297572	171
bw2004-035	8/30/2004	1,220	-109.413763	40.295540	376

Table 2 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2004-036	8/30/2004	1,220	-109.430011	40.298177	140
bw2004-037	8/30/2004	1,220	-109.435550	40.300962	10,636
bw2004-038	8/30/2004	1,220	-109.436804	40.300486	134
bw2004-039	8/30/2004	1,220	-109.441282	40.302808	221
bw2004-040	8/30/2004	1,220	-109.450863	40.309626	796
bw2004-041	8/30/2004	1,220	-109.453712	40.309614	13
bw2004-042	8/30/2004	1,220	-109.455205	40.309288	831
bw2004-043	8/30/2004	1,220	-109.455367	40.309487	148
bw2004-044	8/30/2004	1,220	-109.470901	40.311263	546
bw2004-045	8/30/2004	1,220	-109.471074	40.310923	92
bw2004-046	8/30/2004	1,220	-109.473517	40.312853	1,101
bw2004-047	8/30/2004	1,220	-109.476688	40.312825	14
bw2004-048	8/30/2004	1,220	-109.477939	40.312407	162
bw2004-049	8/30/2004	1,220	-109.479750	40.313245	532
bw2004-050	8/30/2004	1,220	-109.479432	40.313326	235
bw2004-051	8/30/2004	1,220	-109.486093	40.313824	657
bw2004-052	8/30/2004	1,220	-109.487087	40.315239	2,526
bw2004-053	8/30/2004	1,220	-109.490487	40.303923	1,266
bw2004-054	8/30/2004	1,220	-109.492493	40.303764	73
bw2004-055	8/30/2004	1,220	-109.492662	40.303495	71
bw2004-056	8/30/2004	1,220	-109.494041	40.300855	1,104
bw2004-057	8/30/2004	1,220	-109.494577	40.300298	51
bw2004-058	8/30/2004	1,220	-109.501287	40.297534	232
bw2004-059	8/30/2004	1,220	-109.501656	40.298031	225
bw2004-060	8/30/2004	1,220	-109.493467	40.270325	1,003
bw2004-061	8/30/2004	1,220	-109.493330	40.266686	1,303
bw2004-062	8/30/2004	1,220	-109.494185	40.266730	45
bw2004-063	8/30/2004	1,220	-109.498585	40.260829	2,169
bw2004-064	8/30/2004	1,220	-109.499253	40.257388	633
bw2004-065	8/30/2004	1,220	-109.502923	40.254264	1,120
bw2004-066	8/30/2004	1,220	-109.503108	40.253968	77
bw2004-067	8/30/2004	1,220	-109.577839	40.249062	595
bw2004-068	8/30/2004	1,220	-109.578916	40.241080	2,450
bw2004-069	8/30/2004	1,220	-109.581251	40.239989	288
bw2004-070	8/30/2004	1,220	-109.594201	40.243428	1,705
bw2004-071	8/30/2004	1,220	-109.599435	40.241916	108

Table 2 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2004-072	8/30/2004	1,220	-109.595409	40.232347	852
bw2004-073	8/30/2004	1,220	-109.585540	40.220624	159
bw2004-074	8/30/2004	1,220	-109.585126	40.214035	546
bw2004-075	8/30/2004	1,220	-109.585007	40.209460	777
bw2004-076	8/30/2004	1,220	-109.587381	40.201179	6,454
bw2004-077	8/30/2004	1,220	-109.590864	40.195728	2,663
bw2004-078	8/30/2004	1,220	-109.597759	40.195524	384
bw2004-079	8/30/2004	1,220	-109.609570	40.195860	38
bw2004-080	8/30/2004	1,220	-109.610247	40.194848	1,385
bw2004-081	8/30/2004	1,220	-109.613863	40.194284	210
bw2004-082	8/30/2004	1,220	-109.614726	40.195457	246
bw2004-083	8/30/2004	1,220	-109.617181	40.193514	558
bw2004-084	8/30/2004	1,220	-109.618178	40.190370	1,802
bw2004-085	8/30/2004	1,220	-109.619497	40.188917	160
bw2004-086	8/30/2004	1,220	-109.613319	40.183016	680
bw2004-087	8/30/2004	1,220	-109.608890	40.182522	282
bw2004-088	8/30/2004	1,220	-109.607008	40.181333	184
bw2004-089	8/30/2004	1,220	-109.597418	40.182148	3,472
bw2004-090	8/30/2004	1,220	-109.594098	40.182878	101
bw2004-091	8/30/2004	1,220	-109.593523	40.183203	381
bw2004-092	8/30/2004	1,220	-109.589276	40.186078	717
bw2004-093	8/30/2004	1,220	-109.583412	40.187191	198
bw2004-094	8/30/2004	1,220	-109.571435	40.186160	1,599
bw2004-095	8/30/2004	1,220	-109.570730	40.183127	44
bw2004-096	8/30/2004	1,220	-109.573648	40.165755	10,837
bw2004-097	8/30/2004	1,220	-109.584765	40.155900	1,496
bw2004-098	8/30/2004	1,220	-109.585952	40.156477	106
bw2004-099	8/30/2004	1,220	-109.586540	40.154609	2,774
bw2004-100	8/30/2004	1,220	-109.590525	40.152258	1,471
bw2004-101	8/30/2004	1,220	-109.606270	40.155970	3,430
bw2004-102	8/30/2004	1,220	-109.608680	40.154894	3,472
bw2004-103	8/30/2004	1,220	-109.618423	40.150301	763
bw2004-104	8/30/2004	1,220	-109.623582	40.149264	3,073
bw2004-105	8/30/2004	1,220	-109.625356	40.123538	3,441
bw2004-106	8/30/2004	1,220	-109.627367	40.121989	282
bw2004-107	8/30/2004	1,220	-109.624771	40.121334	363

Table 2 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2004-108	8/30/2004	1,220	-109.627873	40.118708	3,074
bw2004-109	8/30/2004	1,220	-109.627716	40.112229	318
Number of backwaters					109
Mean backwater size (m ²)					1,143
Standard deviation backwater size (m ²)					1,771
Total backwater area (m ²)					124,588

TABLE 3 Delineated Backwater Characteristics in 2006

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2006-001	7/14/2006	2,090	-109.243803	40.406053	1,199
bw2006-002	7/14/2006	2,090	-109.252389	40.412003	931
bw2006-003	7/14/2006	2,090	-109.254129	40.414859	4,451
bw2006-004	7/14/2006	2,090	-109.253734	40.417224	415
bw2006-005	7/14/2006	2,090	-109.254014	40.418223	567
bw2006-006	7/14/2006	2,090	-109.271349	40.407437	217
bw2006-007	7/14/2006	2,090	-109.284081	40.398212	442
bw2006-008	7 /14/2006	2,090	-109.308838	40.433852	161
bw2006-009	7/14/2006	2,090	-109.315140	40.435021	47
bw2006-010	7/14/2006	2,090	-109.324879	40.436897	792
bw2006-011	7/14/2006	2,090	-109.328467	40.428870	1,165
bw2006-012	7/14/2006	2,090	-109.329818	40.406758	3,373
bw2006-013	7/14/2006	2,090	-109.332900	40.398862	2,000
bw2006-014	7/14/2006	2,090	-109.327458	40.390603	102
bw2006-015	7/14/2006	2,090	-109.324590	40.389885	67
bw2006-016	7 /14/2006	2,090	-109.324005	40.382408	624
bw2006-017	7/14/2006	2,090	-109.327493	40.381123	6,432
bw2006-018	7/14/2006	2,090	-109.331181	40.379447	1,890
bw2006-019	7/14/2006	2,090	-109.333662	40.369329	33
bw2006-020	7/14/2006	2,090	-109.333536	40.367016	153
bw2006-021	7/14/2006	2,090	-109.333331	40.366911	51
bw2006-022	7/14/2006	2,090	-109.336017	40.365052	225
bw2006-023	7/14/2006	2,090	-109.334487	40.364043	20
bw2006-024	7/14/2006	2,090	-109.346797	40.352037	5,663
bw2006-025	7/14/2006	2,090	-109.352774	40.346880	390
bw2006-026	7/14/2006	2,090	-109.356004	40.344708	508
bw2006-027	7/14/2006	2,090	-109.357052	40.334791	3,809
bw2006-028	7/14/2006	2,090	-109.370881	40.328469	2,503
bw2006-029	7/14/2006	2,090	-109.371564	40.326663	1,162
bw2006-030	7/14/2006	2,090	-109.375240	40.326327	1,653
bw2006-033	7/14/2006	2,090	-109.377432	40.325409	6,271
bw2006-031	7/14/2006	2,090	-109.376959	40.328185	354
bw2006-032	7/14/2006	2,090	-109.378411	40.326840	28
bw2006-034	7/14/2006	2,090	-109.385639	40.324975	2,916
bw2006-035	7/14/2006	2,090	-109.388115	40.321587	1,766
bw2006-036	7/14/2006	2,090	-109.388737	40.319728	2,020

Table 3 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2006-037	7/14/2006	2,090	-109.392681	40.319195	2,255
bw2006-038	7/14/2006	2,090	-109.393697	40.319254	2,175
bw2006-039	7 /14/2006	2,090	-109.397194	40.316479	122
bw2006-040	7/14/2006	2,090	-109.401298	40.308946	237
bw2006-041	7/14/2006	2,090	-109.403222	40.307866	24
bw2006-042	7/14/2006	2,090	-109.405063	40.306498	913
bw2006-043	7/14/2006	2,090	-109.408075	40.304225	106
bw2006-044	7/14/2006	2,090	-109.408218	40.299292	380
bw2006-045	7/14/2006	2,090	-109.410721	40.297860	248
bw2006-046	7/14/2006	2,090	-109.410973	40.297993	85
bw2006-047	7/14/2006	2,090	-109.421551	40.296164	36
bw2006-048	7/14/2006	2,090	-109.430506	40.298563	775
bw2006-049	7/14/2006	2,090	-109.437068	40.299638	501
bw2006-050	7/14/2006	2,090	-109.442775	40.304854	146
bw2006-051	7/14/2006	2,090	-109.443013	40.304645	138
bw2006-052	7/14/2006	2,090	-109.448267	40.306747	1,566
bw2006-053	7 /14/2006	2,090	-109.452103	40.309394	1,324
bw2006-054	7/14/2006	2,090	-109.456653	40.310880	1,387
bw2006-055	7/14/2006	2,090	-109.463155	40.309891	393
bw2006-056	7/14/2006	2,090	-109.463623	40.309233	1,016
bw2006-057	7/14/2006	2,090	-109.463245	40.311372	38
bw2006-058	7/14/2006	2,090	-109.463767	40.311460	113
bw2006-059	7/14/2006	2,090	-109.472295	40.312350	1,937
bw2006-060	7/14/2006	2,090	-109.481330	40.315717	4,204
bw2006-061	7/14/2006	2,090	-109.488015	40.307559	7,125
bw2006-062	7/14/2006	2,090	-109.488514	40.304402	446
bw2006-063	7/14/2006	2,090	-109.495087	40.300051	1,427
bw2006-064	7/14/2006	2,090	-109.500342	40.297690	49
bw2006-065	7/14/2006	2,090	-109.503133	40.297261	283
bw2006-066	7/14/2006	2,090	-109.505753	40.299783	268
bw2006-067	7/14/2006	2,090	-109.510383	40.302792	3,639
bw2006-068	7/14/2006	2,090	-109.513063	40.302392	351
bw2006-069	7/14/2006	2,090	-109.514754	40.303344	1,092
bw2006-070	7/14/2006	2,090	-109.521185	40.302576	582
bw2006-071	7/14/2006	2,090	-109.520836	40.295046	364
bw2006-072	7/14/2006	2,090	-109.522395	40.286777	86
bw2006-073	7/14/2006	2,090	-109.496672	40.279205	380

Table 3 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2006-074	7/14/2006	2,090	-109.494234	40.275104	143
bw2006-075	7/14/2006	2,090	-109.493017	40.272311	2,621
bw2006-076	7/14/2006	2,090	-109.495620	40.266215	8,387
bw2006-077	7/14/2006	2,090	-109.498281	40.261984	765
bw2006-078	7/14/2006	2,090	-109.496092	40.260754	1,136
bw2006-079	7/14/2006	2,090	-109.500350	40.258978	1,332
bw2006-080	7/14/2006	2,090	-109.502993	40.254033	942
bw2006-081	7/14/2006	2,090	-109.503093	40.253644	60
bw2006-082	7/14/2006	2,090	-109.511392	40.247456	46
bw2006-083	7/14/2006	2,090	-109.518691	40.242665	4,620
bw2006-084	7/14/2006	2,090	-109.522772	40.242723	41
bw2006-085	7/14/2006	2,090	-109.530507	40.247719	878
bw2006-086	7/14/2006	2,090	-109.533555	40.251452	192
bw2006-087	7/14/2006	2,090	-109.538556	40.261116	166
bw2006-088	7/14/2006	2,090	-109.537466	40.263821	1,834
bw2006-089	7/14/2006	2,090	-109.540631	40.266453	970
bw2006-090	7/14/2006	2,090	-109.542230	40.267974	463
bw2006-091	7/14/2006	2,090	-109.542834	40.270527	37
bw2006-092	7/14/2006	2,090	-109.544021	40.276439	78
bw2006-093	7/14/2006	2,090	-109.544092	40.278521	26
bw2006-094	7/14/2006	2,090	-109.540398	40.285391	1,310
bw2006-095	7/14/2006	2,090	-109.554425	40.284007	2,334
bw2006-096	7/14/2006	2,090	-109.557697	40.282075	688
bw2006-097	7/14/2006	2,090	-109.562821	40.279506	301
bw2006-098	7/14/2006	2,090	-109.567698	40.276831	52
bw2006-099	7/14/2006	2,090	-109.577003	40.276663	453
bw2006-100	7/14/2006	2,090	-109.578688	40.275966	792
bw2006-101	7/14/2006	2,090	-109.583718	40.270814	208
bw2006-102	7/14/2006	2,090	-109.586658	40.270274	659
bw2006-103	7/14/2006	2,090	-109.590748	40.269842	22
bw2006-104	7/14/2006	2,090	-109.592008	40.268894	39
bw2006-105	7/14/2006	2,090	-109.592505	40.268420	33
bw2006-106	7/14/2006	2,090	-109.596825	40.262385	147
bw2006-107	7/14/2006	2,090	-109.594657	40.260066	437
bw2006-108	7/14/2006	2,090	-109.590652	40.254168	1,087
bw2006-109	7/14/2006	2,090	-109.588032	40.254571	680
bw2006-110	7/14/2006	2,090	-109.581509	40.249400	90

Table 3 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2006-111	7/14/2006	2,090	-109.574325	40.250653	1,262
bw2006-112	7/14/2006	2,090	-109.569272	40.250537	4,124
bw2006-113	7/14/2006	2,090	-109.569797	40.247102	417
bw2006-114	7/14/2006	2,090	-109.578444	40.240138	69
bw2006-115	7/14/2006	2,090	-109.588755	40.244157	2,318
bw2006-116	7/14/2006	2,090	-109.592139	40.244063	175
bw2006-117	7/14/2006	2,090	-109.594428	40.245201	894
bw2006-118	7/14/2006	2,090	-109.598624	40.239805	74
bw2006-119	7/14/2006	2,090	-109.595171	40.232363	4,417
bw2006-120	7/14/2006	2,090	-109.593738	40.230896	245
bw2006-121	7/14/2006	2,090	-109.586782	40.223692	1,002
bw2006-122	7/14/2006	2,090	-109.584650	40.201675	30
bw2006-123	7/14/2006	2,090	-109.586412	40.199357	465
bw2006-124	7/14/2006	2,090	-109.590458	40.198279	89
bw2006-125	7/14/2006	2,090	-109.589009	40.196504	389
bw2006-126	7/14/2006	2,090	-109.593111	40.195683	105
bw2006-127	7/14/2006	2,090	-109.601370	40.196247	1,271
bw2006-128	7/14/2006	2,090	-109.603784	40.195558	428
bw2006-129	7/14/2006	2,090	-109.607495	40.196906	2,123
bw2006-130	7/14/2006	2,090	-109.613964	40.193643	114
bw2006-131	7/14/2006	2,090	-109.617619	40.193985	126
bw2006-132	7/14/2006	2,090	-109.617617	40.191682	393
bw2006-133	7/14/2006	2,090	-109.617613	40.185463	2,926
bw2006-134	7/14/2006	2,090	-109.606854	40.181501	704
bw2006-135	7/14/2006	2,090	-109.592117	40.182659	1,872
bw2006-136	7/14/2006	2,090	-109.587601	40.183120	10,524
bw2006-137	7/14/2006	2,090	-109.577982	40.186667	627
bw2006-138	7/14/2006	2,090	-109.571103	40.185786	210
bw2006-139	7/14/2006	2,090	-109.570525	40.173974	107
bw2006-140	7/14/2006	2,090	-109.584243	40.159014	2,854
bw2006-141	7/14/2006	2,090	-109.587895	40.154236	408
bw2006-142	7/14/2006	2,090	-109.600281	40.153114	406
bw2006-143	7/14/2006	2,090	-109.602179	40.153791	314
bw2006-144	7/14/2006	2,090	-109.606071	40.156341	160
bw2006-145	7/15/2006	1,950	-109.631020	40.138415	1,414
bw2006-146	7/15/2006	1,950	-109.630560	40.134142	515
bw2006-147	7/15/2006	1,950	-109.627752	40.118647	5,898

Table 3 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2006-148	7/15/2006	1,950	-109.627778	40.112235	1,054
bw2006-149	7/15/2006	1,950	-109.653462	40.109545	174
bw2006-150	7 /15/2006	2,090	-109.663806	40.106482	209
bw2006-151	7/15/2006	1,950	-109.665535	40.099362	609
bw2006-152	7/15/2006	1,950	-109.653028	40.092735	60
bw2006-153	7/15/2006	1,950	-109.655401	40.090784	432
bw2006-154	7/15/2006	1,950	-109.656226	40.090463	3,138
bw2006-155	7/15/2006	1,950	-109.658603	40.088803	2,690
bw2006-156	7/15/2006	1,950	-109.673229	40.085118	961
Number of backwaters					156
Mean backwater size (m ²)					1,176
Standard deviation backwater size (m ²)					1,708
Total backwater area (m ²)					183,476

TABLE 4 Delineated Backwater Characteristics in 2013

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2013-001	9/18/2013	1,800	-109.244113	40.406060	683
bw2013-002	9/18/2013	1,800	-109.252388	40.411954	655
bw2013-003	9/18/2013	1,800	-109.254023	40.418183	352
bw2013-004	9/18/2013	1,800	-109.256055	40.420339	65
bw2013-005	9/18/2013	1,800	-109.271669	40.409331	227
bw2013-006	9/18/2013	1,800	-109.271331	40.407407	143
bw2013-007	9/18/2013	1,800	-109.289214	40.407379	3,368
bw2013-008	9/18/2013	1,800	-109.289958	40.417790	660
bw2013-009	9/18/2013	1,800	-109.289199	40.420198	970
bw2013-010	9/18/2013	1,800	-109.288343	40.422765	421
bw2013-011	9/18/2013	1,800	-109.298336	40.428689	979
bw2013-012	9/18/2013	1,800	-109.324455	40.435536	149
bw2013-013	9/18/2013	1,800	-109.327540	40.425804	352
bw2013-014	9/18/2013	1,800	-109.329253	40.416667	583
bw2013-015	9/18/2013	1,800	-109.328325	40.409184	4,077
bw2013-016	9/18/2013	1,800	-109.332621	40.404118	1,584
bw2013-017	9/18/2013	1,800	-109.333517	40.402573	388
bw2013-018	9/18/2013	1,800	-109.332328	40.396384	607
bw2013-019	9/18/2013	1,800	-109.327089	40.391722	2,129
bw2013-020	9/18/2013	1,800	-109.325186	40.388697	245
bw2013-021	9/18/2013	1,800	-109.325378	40.382109	486
bw2013-022	9/18/2013	1,800	-109.326906	40.381741	4,319
bw2013-023	9/18/2013	1,800	-109.333742	40.375726	1,129
bw2013-024	9/18/2013	1,800	-109.335256	40.375097	2,572
bw2013-025	9/18/2013	1,800	-109.336147	40.364880	40
bw2013-026	9/18/2013	1,800	-109.344759	40.356379	5,917
bw2013-027	9/18/2013	1,800	-109.352148	40.347860	520
bw2013-028	9/18/2013	1,800	-109.357328	40.345197	82
bw2013-029	11/2/2013	1,660	-109.364531	40.341782	11
bw2013-030	9/18/2013	1,800	-109.358370	40.335797	843
bw2013-031	9/18/2013	1,800	-109.355510	40.331383	173
bw2013-032	9/18/2013	1,800	-109.359542	40.328860	337
bw2013-033	11/2/2013	1,660	-109.367843	40.326783	215
bw2013-034	11/2/2013	1,660	-109.387040	40.324188	196
bw2013-035	11/2/2013	1,660	-109.387274	40.320530	358

Table 4 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2013-036	11/2/2013	1,660	-109.390674	40.318299	104
bw2013-037	11/2/2013	1,660	-109.397286	40.314908	533
bw2013-038	11/2/2013	1,660	-109.401094	40.311587	581
bw2013-039	11/2/2013	1,660	-109.403104	40.311009	105
bw2013-040	11/2/2013	1,660	-109.410808	40.297122	314
bw2013-041	11/2/2013	1,660	-109.434877	40.301160	3,166
bw2013-042	11/2/2013	1,660	-109.444707	40.306005	7,057
bw2013-043	11/2/2013	1,660	-109.452233	40.310368	3,257
bw2013-044	11/2/2013	1,660	-109.458677	40.309619	1,670
bw2013-045	11/2/2013	1,660	-109.469626	40.310648	448
bw2013-046	11/2/2013	1,660	-109.478890	40.314640	3,898
bw2013-047	11/2/2013	1,660	-109.505977	40.299878	1,251
bw2013-048	11/2/2013	1,660	-109.517074	40.303703	4,680
bw2013-049	11/2/2013	1,660	-109.519735	40.303580	859
bw2013-050	11/2/2013	1,660	-109.521543	40.296044	310
bw2013-051	11/2/2013	1,660	-109.522066	40.294444	115
bw2013-052	11/2/2013	1,660	-109.516336	40.281095	128
bw2013-053	11/2/2013	1,660	-109.494352	40.265889	301
bw2013-054	11/2/2013	1,660	-109.493839	40.265431	268
bw2013-055	11/2/2013	1,660	-109.499068	40.261421	4,517
bw2013-056	11/2/2013	1,660	-109.504924	40.253188	1,039
bw2013-057	11/2/2013	1,660	-109.522877	40.242653	5,395
bw2013-058	11/2/2013	1,660	-109.535470	40.253804	1,714
bw2013-059	11/2/2013	1,660	-109.537185	40.257817	649
bw2013-060	11/2/2013	1,660	-109.542231	40.268702	772
bw2013-061	11/2/2013	1,660	-109.544870	40.275841	430
bw2013-062	11/2/2013	1,660	-109.545644	40.276542	3,282
bw2013-063	11/2/2013	1,660	-109.553176	40.285585	928
bw2013-064	11/2/2013	1,660	-109.594455	40.259733	385
bw2013-065	11/2/2013	1,660	-109.587580	40.253682	1,136
bw2013-066	11/2/2013	1,660	-109.588007	40.252375	496
bw2013-067	11/2/2013	1,660	-109.583847	40.248758	458
bw2013-068	11/2/2013	1,660	-109.578882	40.248890	896
bw2013-069	11/2/2013	1,660	-109.595313	40.242353	212
bw2013-070	11/2/2013	1,660	-109.587947	40.200930	51

Table 4 (Cont.)

Backwater Number	Imagery Date	River Flow at Jensen Gage (cfs)	Location Coordinates (Degree)		Area (m ²)
			E	N	
bw2013-071	11/2/2013	1,660	-109.618681	40.187418	1,679
bw2013-072	11/2/2013	1,660	-109.594532	40.184351	2,674
bw2013-073	11/2/2013	1,660	-109.593628	40.182607	350
bw2013-074	11/2/2013	1,660	-109.588110	40.185241	1,158
bw2013-075	11/2/2013	1,660	-109.581258	40.186617	2,455
bw2013-076	11/2/2013	1,660	-109.569651	40.171799	384
bw2013-077	11/2/2013	1,660	-109.587610	40.155701	953
bw2013-078	11/2/2013	1,660	-109.598226	40.152900	160
bw2013-079	11/2/2013	1,660	-109.604620	40.155578	2,796
bw2013-080	11/2/2013	1,660	-109.608166	40.156363	716
bw2013-081	11/2/2013	1,660	-109.619019	40.152000	72
bw2013-082	11/2/2013	1,660	-109.626729	40.147898	3,296
bw2013-083	11/2/2013	1,660	-109.627765	40.127237	722
bw2013-084	11/2/2013	1,660	-109.625212	40.123059	4,672
bw2013-085	11/2/2013	1,660	-109.661115	40.107892	4,635
bw2013-086	11/2/2013	1,660	-109.665150	40.105491	691
bw2013-087	11/2/2013	1,660	-109.665332	40.104693	1,650
bw2013-088	11/2/2013	1,660	-109.651620	40.093399	2,635
Number of backwaters					88
Mean backwater size (m ²)					1,352
Standard deviation backwater size (m ²)					1,578
Total backwater area (m ²)					118,938

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APPENDIX
IMAGES OF DELINEATED BACKWATERS IN THE
MIDDLE GREEN RIVER IN 2004, 2006, AND 2013

2013-34

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