Evaluation of Adult Sturgeon Migration at the Glenn-Colusa Irrigation District Gradient Facility on the Sacramento River

Green Sturgeon (*Acipenser medirostris*)

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Project Location

The Glenn-Colusa Irrigation District's (GCID) Sacramento River pumping station is located near Hamilton City approximately 100 miles north of the city of Sacramento on the west side of the main stem Sacramento River and 206 river miles upstream from San Francisco Bay (Figure 1). It is located on an oxbow off the main river channel with fish screens positioned upstream of the pumping plant. A Fish Screen Improvement Project (Project) was constructed at the site which included (among other features): 1) an extension of the flat-plate screens; 2) an upgrade to the existing facility; 3) an internal fish bypass system to route fish through pipes and back to an oxbow outlet channel a short distance downstream of the new screens; 4) a rock training wall on the river bank opposite the screens to enhance sweeping velocities past the screens, 5) a flow-control weir in the oxbow channel; and 6) reconfiguration of the oxbow outlet channel to route fish back to the Sacramento River. Additionally, a large-scale gradient facility was constructed on the main stem Sacramento River near the diversion site to ensure long-term reliability of the fish protective facilities (Figure 2).

Introduction

A Fish Protection Evaluation and Monitoring Program (FPEMP) was established prior to completion of the Project. A Guidance Manual was developed for the FPEMP to identify the experimental design, field methods, and equipment necessary to evaluate the biological performance of the new fish screen structure and gradient facility (Montgomery Watson et al. 2000). The cooperating agencies developed and agreed to its contents at the GCID Technical Oversight Committee (TOC) Meeting No. 4 on January 30, 2001. The Guidance Manual outlined studies to evaluate overall fish survival at the fish screens, assess fish passage at the gradient facility, and determine relative abundance and distribution of predatory fish at the gradient site and nearby areas. Results of the biological evaluations of the fish screens are provided in Vogel (2008) and results of the predatory fish study are provided in Vogel (2004).

The Guidance Manual describes the basic experimental design to evaluate potential delay and blockage of green sturgeon (*Acipenser medirostris*) and white sturgeon (*Acipenser transmontanus*) at the gradient facility. The goal was to tag at least 30 adult sturgeon each year for three years. This goal was based on the need to acquire a sufficiently large database and encompass a wide range of flow conditions at the gradient facility. The original plan was to capture sturgeon within approximately 5-10 miles downstream of the gradient site, tag the fish with radio transmitters, and monitor their movements as they migrate up through the study area to determine potential delay and blockage. A pilot-level study was conducted during 2002 to refine the field protocols in advance of the initial study conducted in 2003. No study was conducted in 2004. In 2005 and 2006, the TOC modified the study design to employ the use of acoustic transmitters and receivers to monitor sturgeon migration instead of the use of radio telemetry. This report describes results of the three-year study.

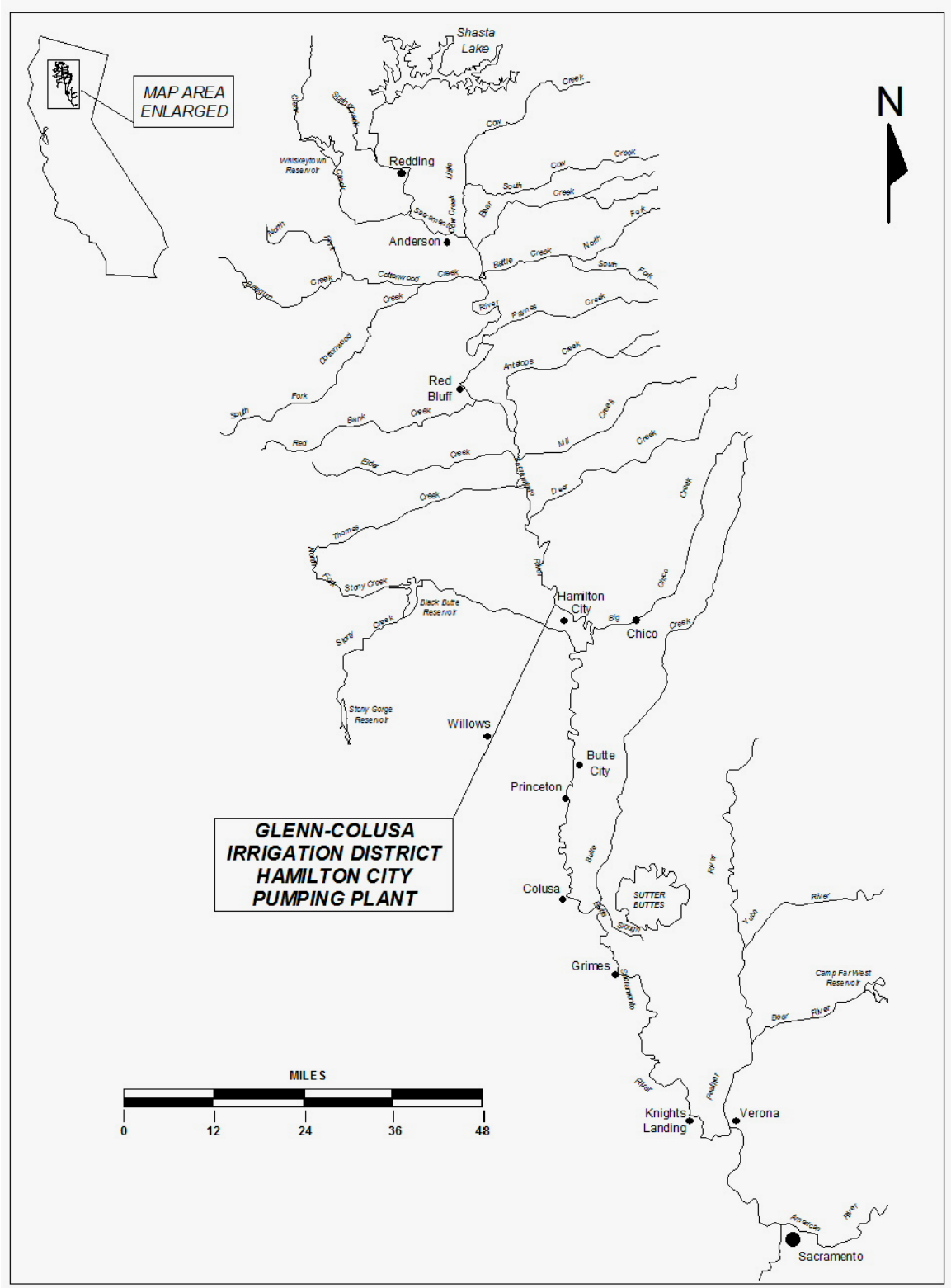

Figure 1. Location of the Glenn-Colusa Irrigation District Hamilton City Pumping Plant on the Sacramento River.

Figure 2. The GCID Hamilton City Pumping Plant and associated features of the Fish Screen Improvement Project.

Methods

2003 Study

All sturgeon used for radio telemetry in the gradient facility evaluation during 2003 were captured by hook and line angling. Captured fish were externally tagged with radio transmitters and released downstream of the gradient facility. The 31-gram, 48-49 MHz, model F2090 Advanced Telemetry Systems, Inc. transmitters were activated at the time of tagging. Radio tags were externally attached by inserting two hypodermic needles just under the sturgeon's dorsal fin, threading two stainless steel wires on the tag harness through the needles and crimping the wires on the opposite side of the fish with circular, plastic plates to hold the tag in place (Figure 3). Radio tags were labeled with a return address and phone number to encourage sport anglers to contact us and receive a reward for harvest data.

Figure 3. Placement of an external radio tag below the dorsal fin on a white sturgeon.

To determine the routes of fish passage at the gradient facility, initially four, and ultimately five, fixed-station, Advanced Telemetry Systems, Inc. Model 05041A electronic data loggers and Model R2100 receivers with Yagi antennae (Figure 2) were placed at strategic locations near the site. Those sites included: 1) McIntosh Landing; 2) mid-island (Montgomery Island) to detect fish approaching the gradient facility; 3) immediately downstream of the gradient facility; 4) the oxbow channel at the flow control weir to detect fish using the oxbow as a migration route; and 5) the upstream tip of Montgomery Island (north island) to detect fish after migrating past the gradient facility or through the oxbow channel (Figure 5). After discussions among the TOC members, the telemetry station just downstream of the gradient facility was added to acquire additional data on sturgeon passage. The data was post-processed filtered to aid in blocking out electronic interference from external sources (e.g., pumps, outboard engines, etc).

Figure 4. Fixed-station electronic data logger used in the fish radio-telemetry studies. Station shown was placed downstream of the gradient facility (mid-island).

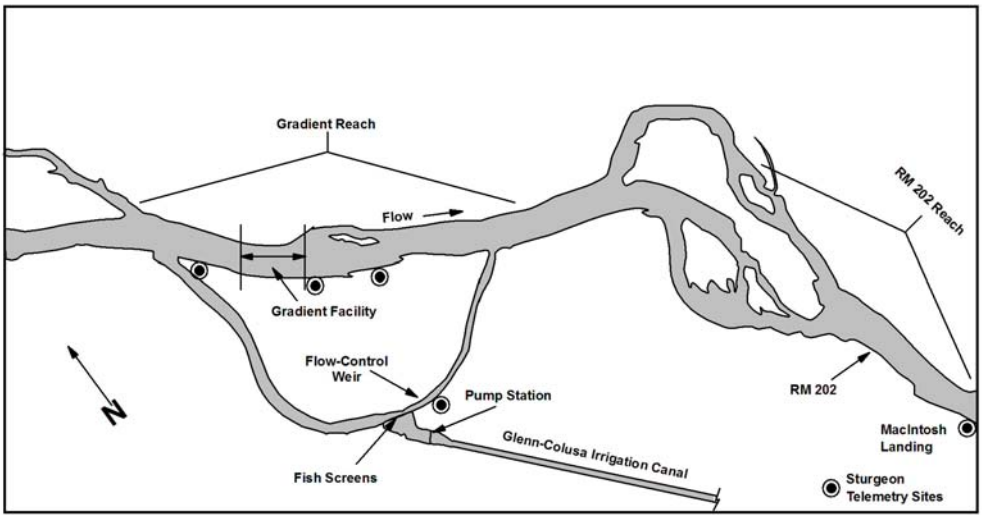

Figure 5. Location of the fixed-station, data loggers used in the 2003 sturgeon radio-telemetry investigations.

2005 and 2006 Studies

All sturgeon used for acoustic telemetry in the 2005 and 2006 gradient facility evaluations were captured by hook and line angling at a site a short distance upstream of the gradient facility known to possess adult green sturgeon (based on angling in 2003). Prior attempts to capture sturgeon a short distance downstream of the gradient facility were unsuccessful. Captured fish were internally tagged with acoustic transmitters[1] and released downstream of the gradient facility (Figure 6). The acoustic transmitters were activated at the time of tagging. Acoustic tags were surgically implanted through a small incision on the ventral side of the fish. The incision was closed with sutures and treated with antiseptic and antibiotic. Tagged fish were released near McIntosh Landing downstream and out of detection range of the McIntosh Landing receiver. Other researchers using the same acoustic transmitters at other locations in the Sacramento River and Bay/Delta were notified of the tag codes in the event that detections were logged by their acoustic receivers.

[1] VEMCO transmitters and receivers were used for the study.

Figure 6. Adult green sturgeon tagged with an acoustic transmitter and released downstream of the GCID gradient facility.

To determine the routes of fish passage at the gradient facility during 2005, acoustic receivers (data loggers) with about 100 – 200-yard detection range (Figure 7) were placed at strategic locations downstream and upstream of the gradient facility (Figure 8). At some sites, we deployed multiple receivers in relatively close proximity to ensure adequate coverage for detection of acoustic tags.

Figure 7. Acoustic receiver used in the fish telemetry studies during 2005 and 2006.

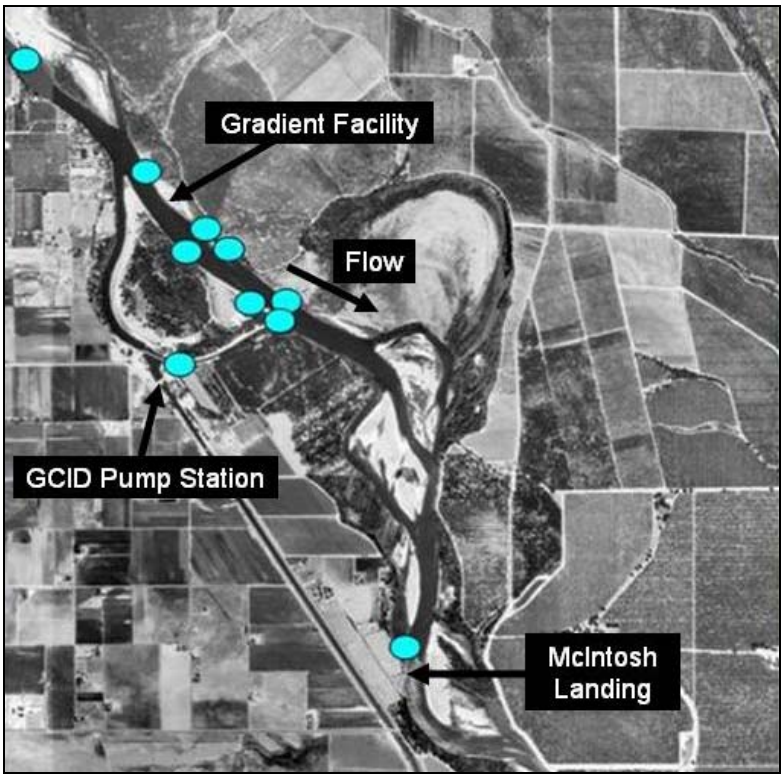

Figure 8. Location of the fixed-station, acoustic data loggers used in the sturgeon telemetry investigation in 2005.

Figure 9 shows the locations of dataloggers during the 2006 study.

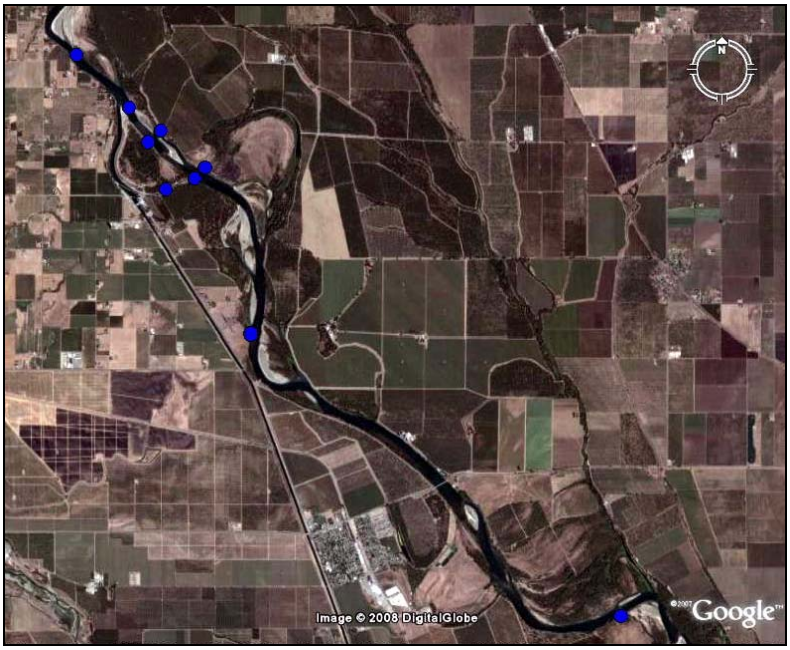

Figure 9. Location of the fixed-station, acoustic data loggers used in the sturgeon telemetry investigation in 2006.

Results and Discussion

2003 Study

The evaluation of sturgeon migration was initiated on January 29, 2003. Installation of four fixed-station data loggers occurred on January 29, 2003; installation of the fifth station just downstream of the gradient occurred on March 28, 2003. From February 14 to November 8, 2003, 11 white sturgeon and 14 green sturgeon were captured and radio tagged. Table 1 provides tagging and release data for the 25 sturgeon. All five data logger stations were removed on November 20, 2003.

Initial attempts to capture sturgeon within a short distance downstream of the gradient were unsuccessful, so angling was performed further downstream to increase the success rate. During the early portion of the evaluation season (February through May), only white sturgeon were captured. None of the white sturgeon migrated upstream as far as the gradient facility. Two of the white sturgeon were subsequently captured by sport anglers downstream of Princeton.

During the summer and fall of 2003, anglers focused fishing efforts on the river reach a short distance upstream of the gradient facility in locations known (from past experience) to be good habitats for green sturgeon. Fourteen green sturgeon were captured in that area, transported downstream of the gradient facility, radio-tagged, and released. Although these sturgeon had previously passed the gradient site, the flow conditions at time of original passage and potential delay in passage were unknown. It was believed that telemetry data for subsequent passage would provide useful information on potential delay and blockage for known flow conditions.

Of the 14 green sturgeon that were radio-tagged and released downstream of the gradient facility, 7 sturgeon approached and passed the site (Table 1). The remaining fish dropped back downstream from the release location. Figures 10 through 15 and Table 2 provide data for six of the seven[2] green sturgeon that passed the gradient facility. In most instances, because of close proximity, there was data overlap between the two data loggers just upstream (north island) and downstream of the gradient facility and the two data loggers just downstream of the gradient facility and mid-island, but not between the north island and mid-island loggers. This allowed sequential depiction of fish passage shown in the following figures.

[2] One of the seven sturgeon had insufficient data collected on the electronic data loggers due to a malfunction on the north island logger and an un-programmed logger at McIntosh Landing. However, fish passage was confirmed through mobile reconnaissance and detection upstream of the gradient. Based on logged detections on two of the island data loggers immediately downstream of the gradient, the fish was presumed to have passed the gradient during late evening on August 19, 2003.

Table 1. Capture and release information for radio-tagged white and green sturgeon in 2003.						
Date of Capture/ Tagging	**Capture Location**	**Release Location by River Mile (RM)**	**Frequency (MHz)**	**Sturgeon Species**	**Length (inches)**	**Passed Gradient Facility?**
2/14/2003	1.5 miles below Meridian	RM 133	48.692	White	72	No
2/15/2003	1.5 miles below Meridian	RM 133	48.221	White	61	No
3/2/2003	Grimes	RM 125	48.951	White	52	No
3/3/2003	2 miles north of Grimes	RM 126	48.891	White	63	No
3/13/2003	2 miles below Princeton	RM 162	48.712	White	65	No
3/19/2003	2 miles below Princeton	RM 162	48.771	White	75	No
3/20/2003	Grimes / Lupe's Bend	RM 125	48.201	White	66	No
3/23/2003	Grimes / Lupe's Bend	RM 125	48.971	White	66	No
4/10/2003	3 miles below Princeton	RM 161	48.731	White	60	No
4/10/2003	3 miles below Princeton	RM 161	48.611	White	58	No
5/13/2003	2 miles below Princeton	RM 162	48.501	White	76	No
7/16/2003	8 miles upstream of Highway 32	RM 205	49.421	Green	94	Yes
7/31/2003	8 miles upstream of Highway 32	RM 205	49.501	Green	76	Yes
8/4/2003	8 miles upstream of Highway 32	RM 205	49.991	Green	92.5	Yes
8/8/2003	8 miles upstream of Highway 32	RM 201	48.300	Green	89	No
8/11/2003	8 miles upstream of Highway 32	RM 201	49.621	Green	86	Yes
8/13/2003	8 miles upstream of Highway 32	RM 201	49.521	Green	79	Yes
8/19/2003	8 miles upstream of Highway 32	RM 201	49.541	Green	74	Yes
8/20/2003	8 miles upstream of Highway 32	RM 201	49.870	Green	76	No
8/20/2003	8 miles upstream of Highway 32	RM 201	49.811	Green	84	No
9/6/2003	8 miles upstream of Highway 32	RM 201	49.831	Green	69	Yes
9/26/2003	8 miles upstream of Highway 32	RM 201	49.791	Green	67.5	No
10/18/2003	8 miles upstream of Highway 32	RM 201	49.651	Green	76	No
11/2/2003	8 miles upstream of Highway 32	RM 201	49.440	Green	76	No
11/8/2003	8 miles upstream of Highway 32	RM 201	49.601	Green	68	No

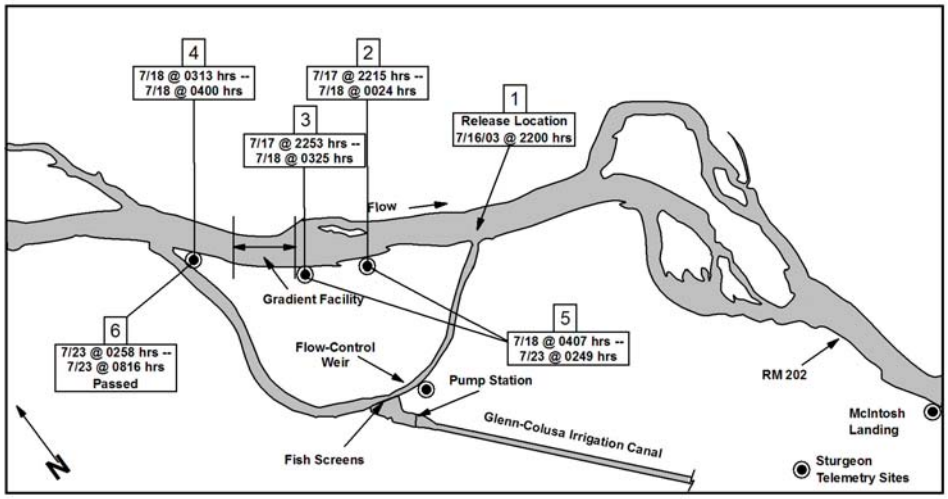

Figure 10. Telemetry data for a green sturgeon radio-tagged with a 49.421 MHz transmitter and released downstream of the gradient facility on July 16, 2003.

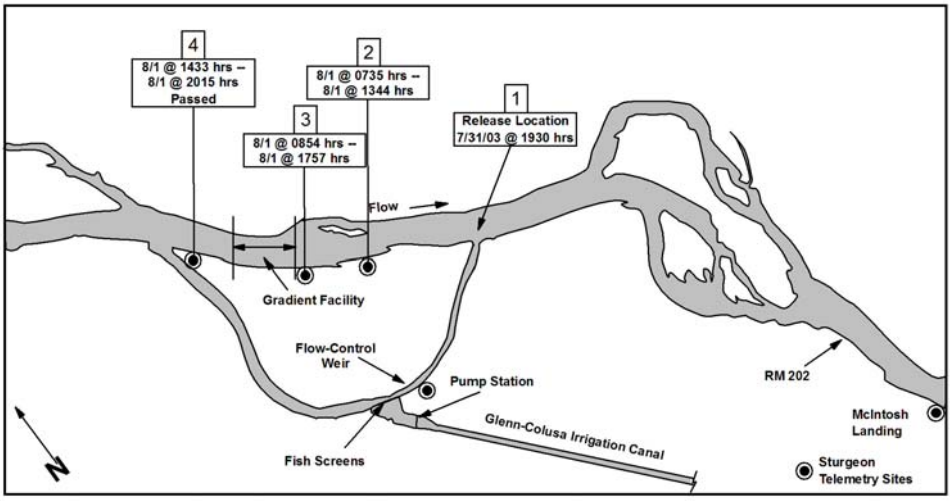

Figure 11. Telemetry data for a green sturgeon radio-tagged with a 49.501 MHz transmitter and released downstream of the gradient facility on July 31, 2003.

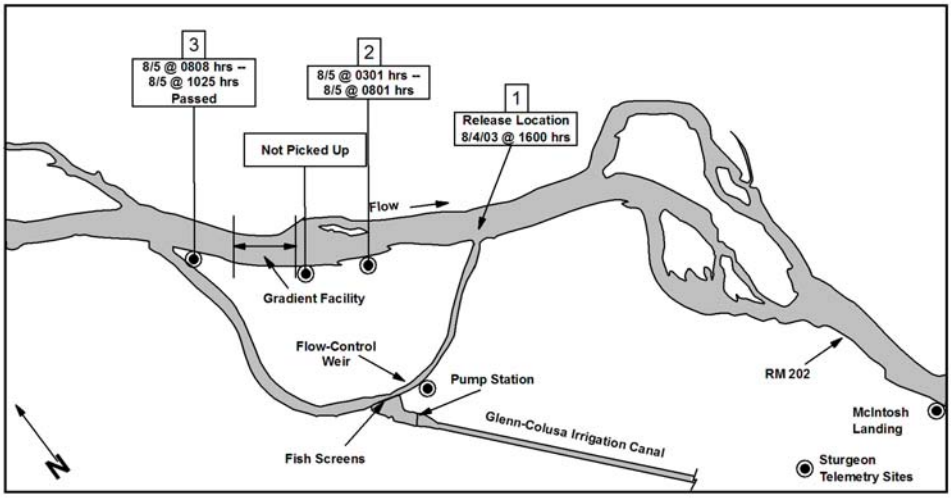

Figure 12. Telemetry data for a green sturgeon radio-tagged with a 49.991 MHz transmitter and released downstream of the gradient facility on August 4, 2003.

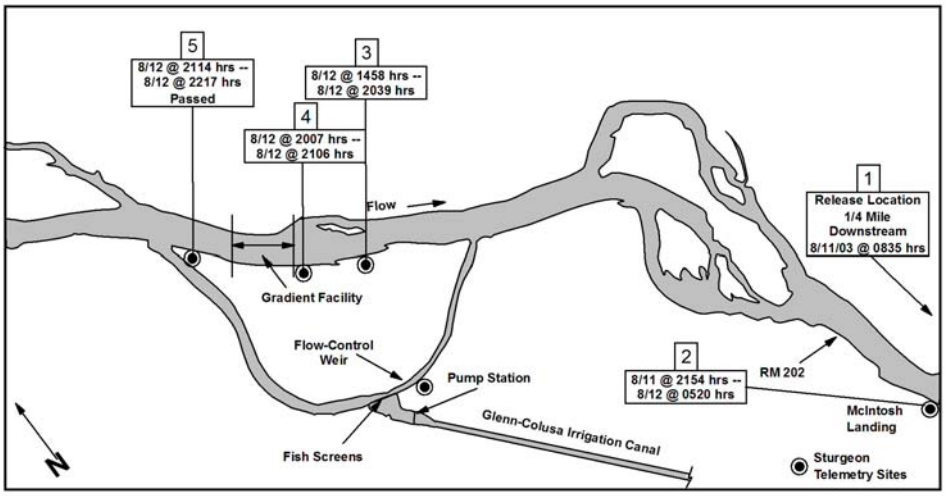

Figure 13. Telemetry data for a green sturgeon radio-tagged with a 49.621 MHz transmitter and released downstream of the gradient facility on August 11, 2003.

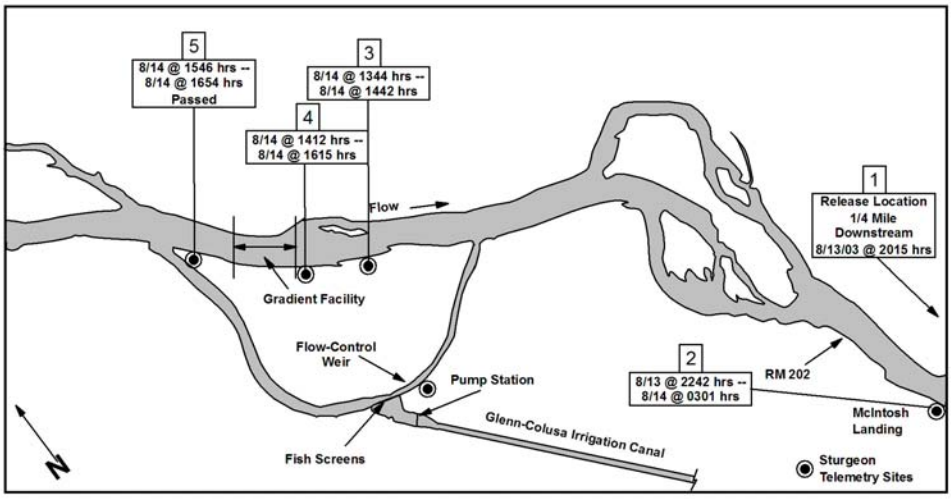

Figure 14. Telemetry data for a green sturgeon radio-tagged with a 49.521 MHz transmitter and released downstream of the gradient facility on August 13, 2003.

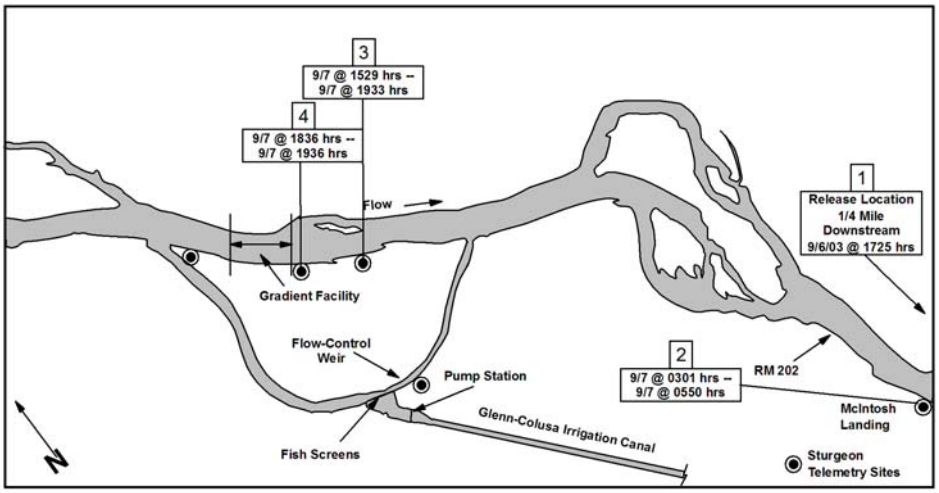

Figure 15. Telemetry data for a green sturgeon radio-tagged with a 49.831 MHz transmitter and released downstream of the gradient facility on September 6, 2003.

Table 2. Migration data for six[1] radio-tagged green sturgeon that passed the GCID gradient facility.

Frequency (MHz)	Release Date/Time	Release Location	Elapsed Time between McIntosh Landing (last detection) and Mid-Island (first detection) (Hrs:Min)	Elapsed Time between Mid-Island (last detection) and u/s of Gradient (last detection[2]) (Hrs:Min)	Gianella Flow (cfs) on Day of Passage	Gianella Flow + Pump Flow (cfs) on Day of Passage
49.421	7/16/2003 22:00	Near oxbow exit	N/A	5:31	11,870 (7/23/03)	14,120
49.501	7/31/2003 19:30	Near oxbow exit	N/A	6:31	12,620 (8/1/03)	14,720
49.991	8/4/2003 16:00	Near oxbow exit	N/A	2:24	12,420 (8/5/03)	14,420
49.621	8/11/2003 8:35	1/4 mile d/s of McIntosh Landing	9:38	1:38	7,642 (8/12/03)	9,692
49.521	8/13/2003 20:15	1/4 mile d/s of McIntosh Landing	10:43	2:12	7,498 (8/14/03)	9,548
49.831	9/6/2003 17:25	1/4 mile d/s of McIntosh Landing	9:39	N/A	6,161 (9/7/03)	7,211

[1] One of the seven sturgeon passing through the gradient facility (49.541 MHz) had insufficient data collected on the electronic data loggers due to a malfunction on the north island logger and an un-programmed logger at McIntosh Landing. However, fish passage was confirmed through mobile reconnaissance and detection upstream of the gradient. Based on logged detections on two of the island data loggers immediately downstream of the gradient, the fish was presumed to have passed the gradient during late evening on August 19, 2003.

[2] The last time of detection was used here because of the close proximity of the data logger to the gradient facility and inability to know exact fish location.

The first sturgeon (49.421 MHz) passing the gradient provided interesting data on movement within the vicinity. Within 1-2 days after release at the oxbow outlet confluence on July 16, 2003, the fish migrated up to and within the gradient but dropped back downstream to just below the gradient where the fish remained for five days (Figure 10). The fish subsequently migrated up through and passed the gradient facility on July 23, 2003.

The second and third sturgeon (49.501 MHz and 49. 991 MHz, respectively) passing through the gradient facility did so within one day after release at the oxbow outlet confluence with the Sacramento River (Figures 11 and 12).

The remaining three sturgeon for which data were available were released downstream of McIntosh Landing (Figures 13 - 15). Time of passage between McIntosh Landing and the mid-island was relatively slow for these fish (approximately 10 hours) over a distance of about 2 miles (Table 2). The estimated average migration rate for these 3 fish was approximately 0.29 feet/second compared to estimated average migration rate of 0.21

feet/second for 5 fish that passed the gradient (a distance of approximately 0.5 miles[3]) (Table 2). However, because the exact location of fish detected by the receivers during migration could not be determined, these migration rates should be considered only general approximations.

Although the sample size (N=7) during the 2003 study was small, there were no occasions of sturgeon approaching the gradient facility and subsequently backing downstream without successful passage which would have indicated potential blockage. None of the radio-tagged sturgeon were detected to have migrated upstream into the oxbow outlet channel to the flow-control weir. There were insufficient data collected among the seven sturgeon that did pass through the gradient to ascertain potential delay in passage. Passage rate appeared to be slow, but it is not known if that was attributable to normal migratory behavior; intermittent periods of sturgeon resting in deep pools could account for slow, average migration rates over extended river reaches.

2005 Study

From July 12 to November 19, 2005, 40 green sturgeon were captured and tagged with acoustic transmitters. Table 3 provides capture and tagging data for the 40 sturgeon. All data logger stations were removed in December 2005.

Table 3. Capture and release information for acoustic-tagged green sturgeon in 2005.

Fish #	Date and Time Captured	Tag ID	Total Length (inches)
1	7/12/2005 20:30	164	84
2	7/15/2005 04:00	158	80
3	7/20/2005 21:15	157	80.5
4	8/1/2005 18:00	163	70
5	8/1/2005 20:00	155	76
6	8/3/2005 14:00	162	76
7	8/4/2005 19:00	153	76
8	8/4/2005 19:45	154	66
9	8/4/2005 20:35	161	80
10	8/6/2005 20:00	160	79
11	8/9/2005 17:00	152	65
12	8/11/2005 19:00	168	74
13	8/12/2005 23:00	159	65
14	8/15/2005 18:20	167	73
15	8/19/2005 18:30	165	81
16	8/19/2005 19:45	156	79
17	8/19/2005 22:00	166	71
18	8/21/2005 17:30	176	78
19	8/24/2005 19:00	175	78
20	8/28/2005 18:00	173	70

[3] Estimated distances between upstream and downstream receiver detections.

Table 3. Capture and release information for acoustic-tagged green sturgeon in 2005.			
Fish #	**Date and Time Captured**	**Tag ID**	**Total Length (inches)**
21	9/8/2005 19:00	177	80
22	9/17/2005 19:30	180	76
23	9/17/2005 21:45	179	82
24	9/18/2005 20:00	171	68
25	9/22/2005 19:00	172	82
26	9/29/2005 13:15	170	68
27	10/1/2005 20:30	151	78
28	10/5/2005 20:30	174	70
29	10/11/2005 21:30	169	70
30	10/19/2005 18:20	178	72
31	10/21/2005 20:15	182	65
32	10/22/2005 22:20	189	64
33	10/24/2005 20:20	188	63.5
34	10/26/2005 21:15	187	78
35	10/29/2005 14:30	181	79
36	10/29/2005 15:40	183	73
37	11/4/2005 13:40	185	73
38	11/5/2005 12:00	184	65
39	11/11/2005 16:20	190	79
40	11/19/2005 14:50	186	74

Of the 40 green sturgeon that were sonic-tagged and released downstream of the gradient facility near McIntosh Land, 11 sturgeon migrated back upstream to southern Montgomery Island (Table 4). Of those 11 fish, five sturgeon continued their upstream migration through the gradient facility (Figures 16 – 20). These five sturgeon exhibited an average migration rate of 0.31 ft/s (range: 0.07 – 0.76 ft/s) from the receiver near McIntosh Landing to south Montgomery Island (i.e., through "natural" riffles) and 0.51 ft/s (range: 0.29 – 0.88 ft/s) from the south island to north island (i.e., through the gradient facility). When including all 11 sturgeon that migrated from McIntosh Landing to south island, the average migration rate was 0.22 ft/s (Table 4).

Table 4. Migration results for 11 green sturgeon caught upstream of the GCID gradient facility and released downstream near McIntosh Landing.

Tag #	Last Detection at McIntosh Landing	1st Detection at South Montgomery Island	Elapsed Time McIntosh Landing to South Montgomery Island	Migration Rate (ft/sec)	Last Detection at South Montgomery Island	1st Detection at North Montgomery Island	Elapsed Time South Montgomery Island to North	Migration Rate (ft/sec)	Gianella Flow (cfs) on Day of Passage	Gianella Flow + Pump Flow (cfs) on Day of Passage
155	8/2/05 @ 1:20:10	8/2/05 @ 4:38:38	3:18:28 (4957)	0.77	8/2/05 @ 4:43:49	8/2/05 @ 6:13:30	1:29:41	0.88	9,265 (8/2/05)	11,597 (8/2/05)
163	8/2/05 @ 10:28:28	8/2/05 @ 22:19:54	11:51:26 (4955)	0.21	8/2/05 @ 22:30:23	8/3/05 @ 3:02:43	4:32:20	0.29	9,411 (8/3/05)	11,776 (8/3/05)
152	8/10/05 @ 4:04:27	8/10/05 @ 11:31:03	7:26:36 (4955)	0.34	8/10/05 @ 11:57:29	8/10/05 @ 13:46:09	1:48:40	0.67	7,990 (8/10/05)	10,390 (8/10/05)
156 (a)	8/21/05 @ 23:08:24	8/23/05 @ 13:10:45	38:02:21 (4955)	0.07						
166 (a)	8/21/05 @ 3:09:27	8/22/05 @ 2:02:30	22:53:03 (4955)	0.11						
167	8/24/05 @ 5:44:59	8/25/05 @ 21:17:12	39:32:13 (4955)	0.06	8/25/05 @ 21:46:40	8/26/05 @ 1:45:22	3:58:42	0.33	7,174 (8/25/05) 7,238 (8/26/05)	9,039 (8/25/05) 9,055 (8/26/05)
180 (b)	9/19/05 @ 2:58:02	9/19/05 @ 21:33:32	18:35:30 (4955)	0.14						
171	9/19/05 @ 5:37:43	9/20/05 @ 0:03:07	18:25:24 (4955)	0.14	9/20/05 @ 1:00:09	9/20/05 @ 4:40:23	3:40:14	0.36	7,318 (9/20/05)	7,976 (9/20/05)
174 (a)	10/9/05 @ 5:02:12	10/10/05 @ 4:57:22	23:55:10 (4955)	0.11						
181 (a)	No data at McIntosh	----	----	----						
187 (b)	No data at McIntosh	----	----	----						

(a) – Fish did not migrate past the south Montgomery Island area.
(b) – Fish migrated up to gradient facility, but did not pass.
18 sturgeon migrated to McIntosh Landing only.
11 sturgeon were not detected on any GCID receiver.

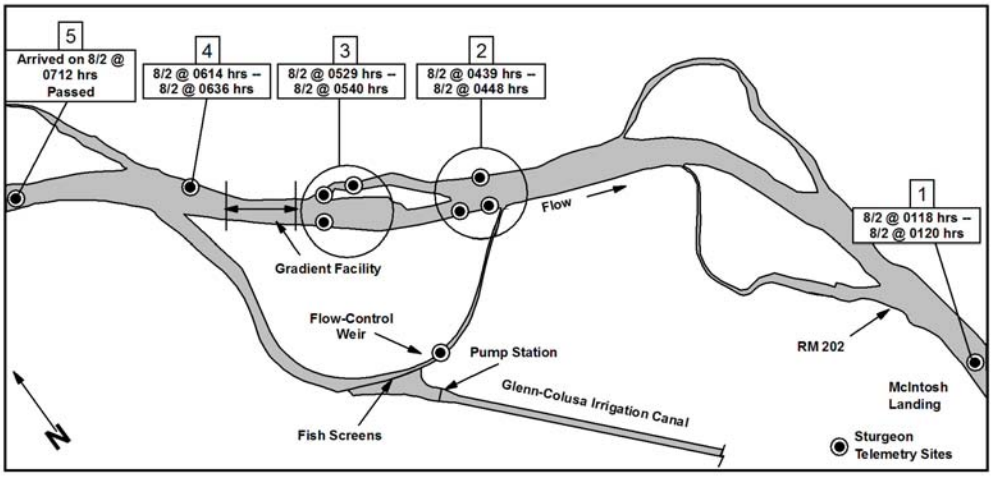

Figure 16. Telemetry data for acoustic-tagged sturgeon no. 155.

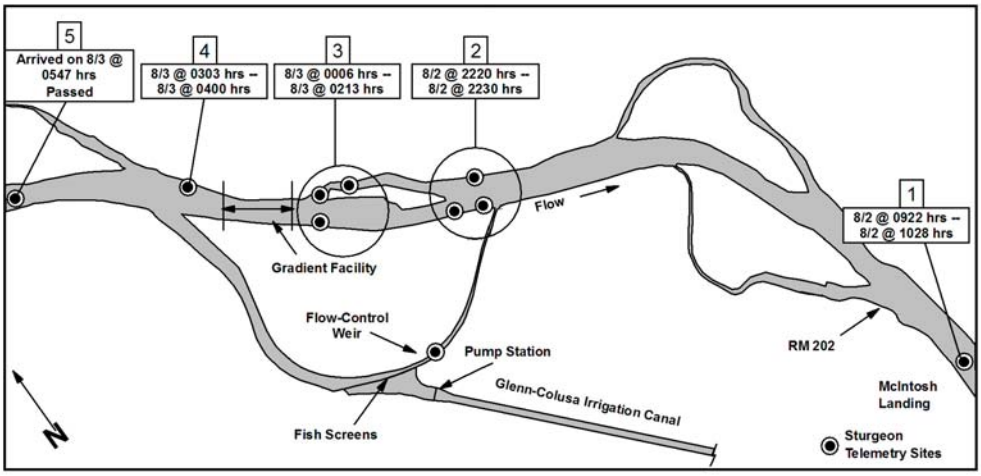

Figure 17. Telemetry data for acoustic-tagged sturgeon no. 163.

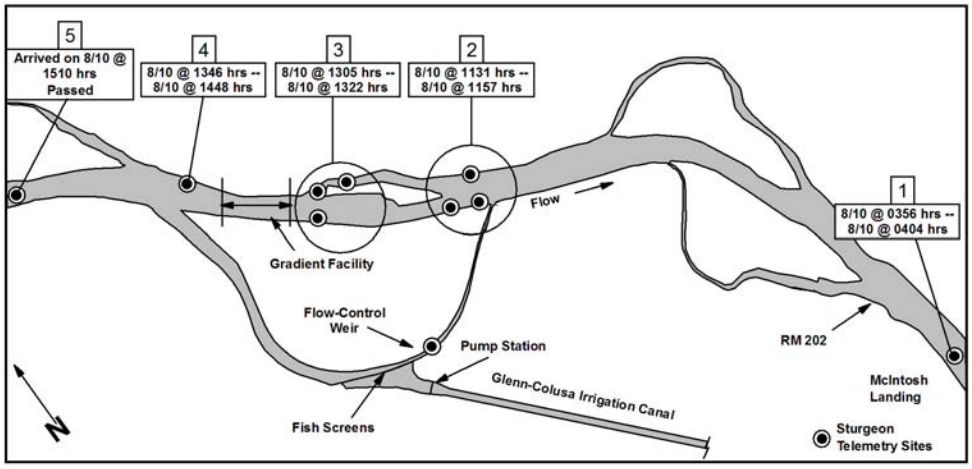

Figure 18. Telemetry data for acoustic-tagged sturgeon no. 152.

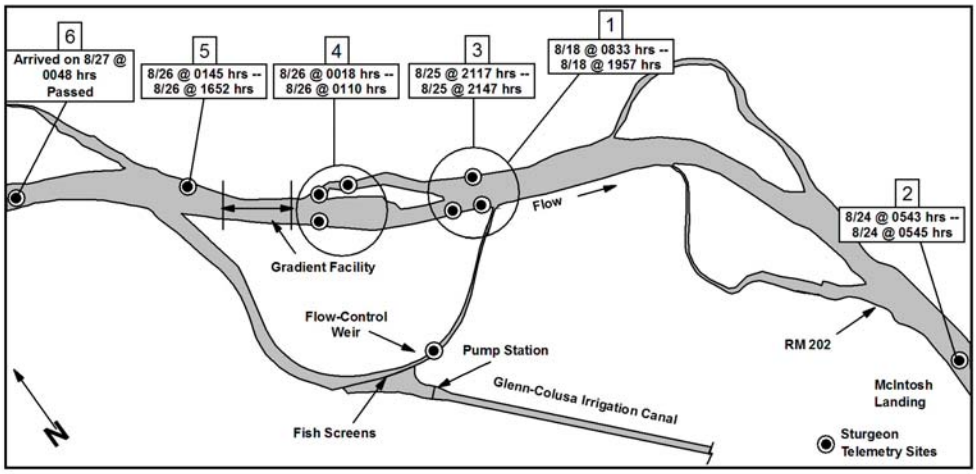

Figure 19. Telemetry data for acoustic-tagged sturgeon no. 167.

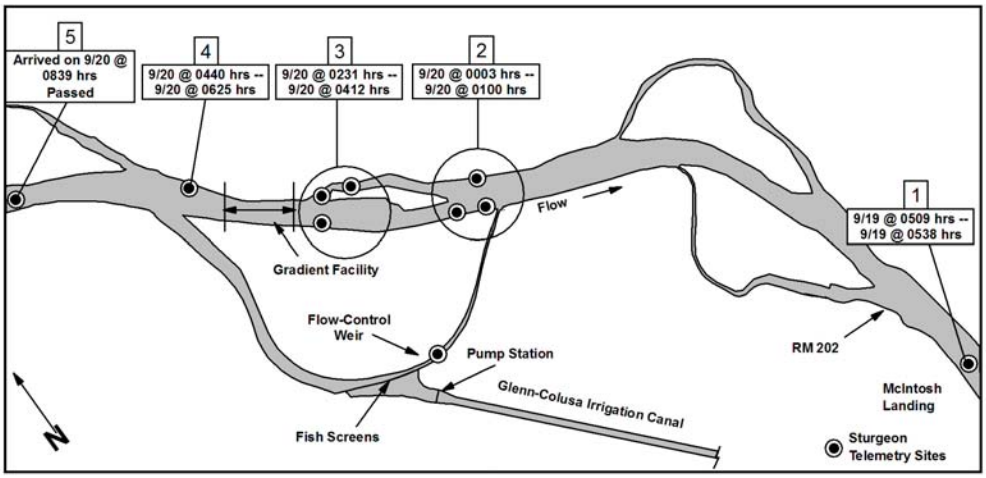

Figure 20. Telemetry data for acoustic-tagged sturgeon no. 171.

Four of the 11 sturgeon migrating up to Montgomery Island did not migrate past the southern portion of island and two sturgeon migrated up to the gradient facility but did not pass the gradient site (Table 4 and Figures 18 - 26). None of the sturgeon were detected to have migrated up to the flow-control weir into the oxbow outlet channel.

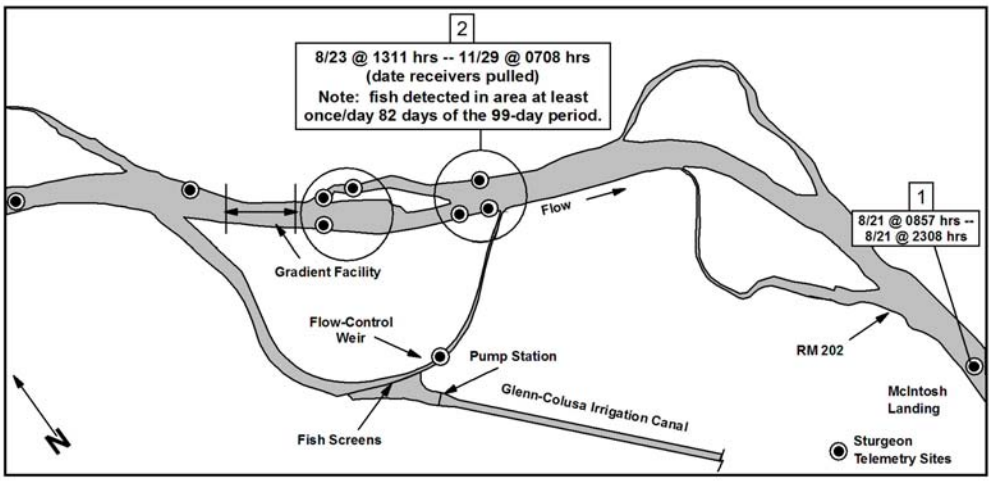

Figure 21. Telemetry data for acoustic-tagged sturgeon no. 156.

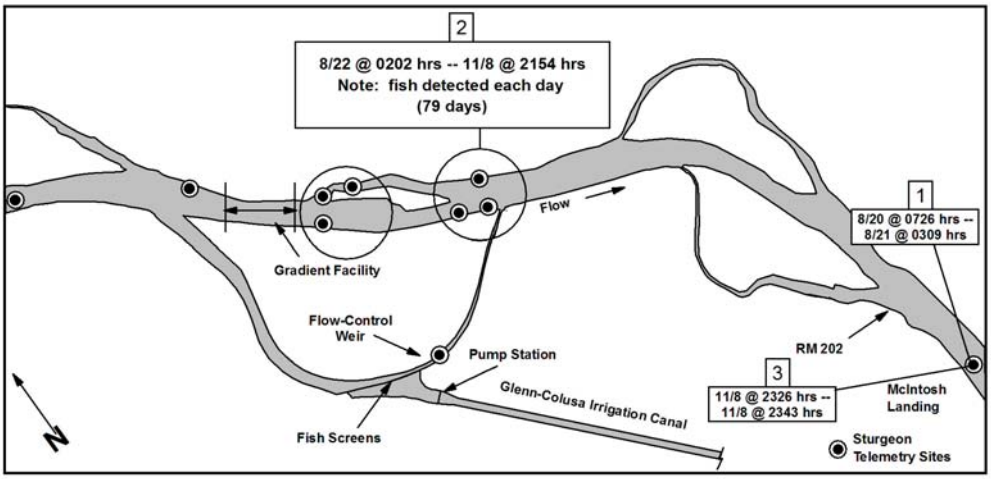

Figure 22. Telemetry data for acoustic-tagged sturgeon no. 166.

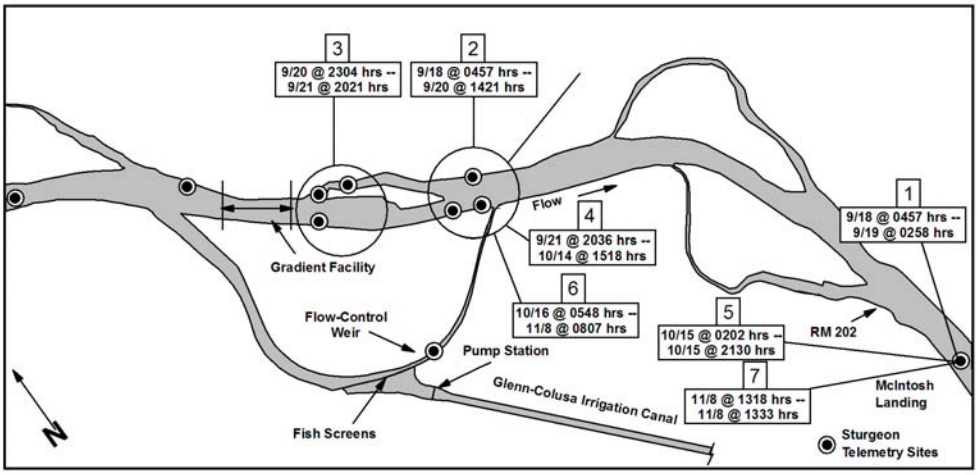

Figure 23. Telemetry data for acoustic-tagged sturgeon no. 180.

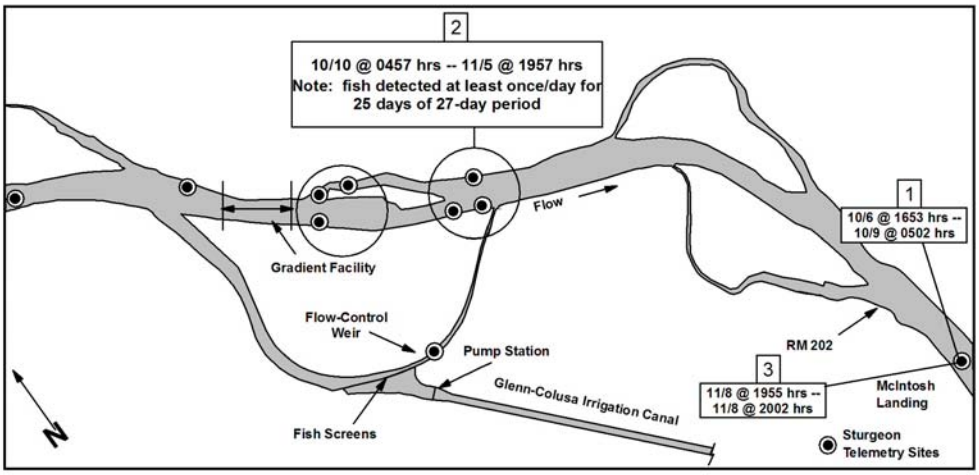

Figure 24. Telemetry data for acoustic-tagged sturgeon no. 174.

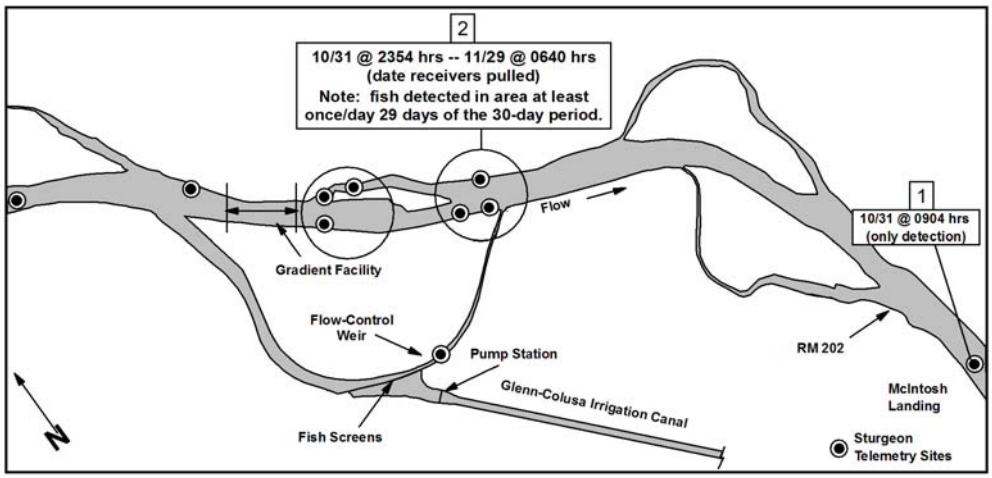

Figure 25. Telemetry data for acoustic-tagged sturgeon no. 181.

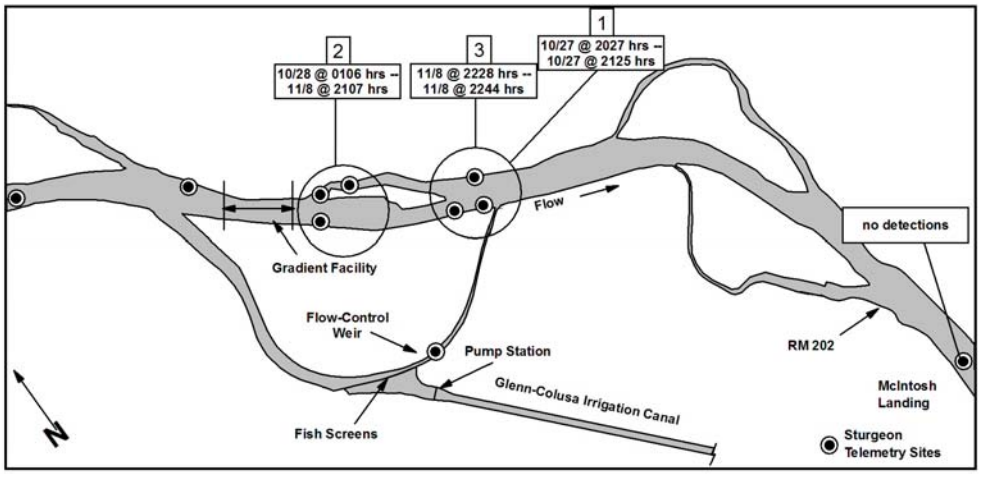

Figure 26. Telemetry data for acoustic-tagged sturgeon no. 187.

Eighteen of the 40 sturgeon migrated up near the downstream-most receiver then moved back downstream. Eleven of the 40 sturgeon moved downstream after release and were never detected on any GCID receiver (Table 4).

2006 Study

From June 14 to October 28, 2006, 54 green sturgeon and one white sturgeon were captured and tagged with acoustic transmitters. Table 5 provides capture and tagging data for the 55 sturgeon. All data logger stations were removed in mid-December 2006.

Table 5. Capture and size information for 54 acoustic-tagged green sturgeon and one white sturgeon (fish no. 3) in 2006.

Fish #	Date and Time Captured	Tag ID	Length (inches)
1	6/14/2006 00:40	216	63
2	6/14/2006 04:05	217	77
3	6/19/2006 20:50	218	67
4	6/27/2006 18:00	219	65
5	6/28/2006 19:45	220	80
6	6/29/2006 16:30	221	81
7	6/30/2006 09:30	222	80
8	6/30/2006 20:10	223	68
9	7/07/2006 16:55	224	83
10	7/12/2006 19:40	225	76
11	7/12/2006 20:55	226	84
12	7/13/2006 13:15	227	74
13	7/13/2006 14:25	228	73
14	7/13/2006 15:18	229	75
15	7/14/2006 08:50	230	88
16	7/16/2006 21:25	231	68
17	7/17/2006 21:55	232	70
18	7/18/2006 22:30	233	78
19	7/19/2006 22:30	234	90
20	7/21/2006 19:00	235	77
21	7/23/2006 21:30	236	82
22	7/24/2006 05:10	237	75
23	7/27/2006 06:30	238	72
24	8/02/2006 17:45	239	75
25	8/04/2006 06:10	240	71
26	8/10/2006 11:40	241	79
27	8/11/2006 09:55	242	76
28	8/14/2006 06:40	243	70
29	8/18/2006 08:10	244	74
30	8/18/2006 22:35	245	82
31	8/22/2006 20:05	246	78
32	8/30/2006 17:25	247	72
33	9/05/2006 16:25	248	75
34	9/06/2006 17:20	249	75

Table 5. Capture and size information for 54 acoustic-tagged green sturgeon and one white sturgeon (fish no. 3) in 2006.			
Fish #	**Date and Time Captured**	**Tag ID**	**Length (inches)**
35	9/12/2006 08:00	250	72
36	9/17/2006 18:10	251	80
37	9/17/2006 20:00	252	70
38	9/18/2006 18:20	253	75
39	9/19/2006 17:25	254	68
40	9/19/2006 19:05	255	74
41	9/20/2006 08:00	25	70
42	9/24/2006 20:45	26	82
43	9/29/2006 15:50	27	72
44	9/29/2006 17:05	28	77
45	10/05/2006 10:32	29	82
46	10/06/2007 18:15	30	75
47	10/06/2006 19:30	31	75
48	10/07/2006 07:50	32	73
49	10/10/2006 19:32	33	85
50	10/12/2006 06:50	34	66
51	10/12/2007 08:35	36	72
52	10/16/2002 15:55	37	62
53	10/24/2006 16:45	38	83
54	10/27/2006 18:15	39	61
55	10/28/2006 15:50	40	69

Of the 55 sturgeon that were sonic-tagged and released downstream of the gradient facility near McIntosh Landing, 24 sturgeon migrated back upstream to southern Montgomery Island. Of those 24 fish, 10 sturgeon continued their upstream migration through the gradient facility. Nine of those fish had sufficient detections on receivers to provide migration rates from south Montgomery Island to north Montgomery Island (i.e., through the gradient facility) (Figures 27 – 35). These nine sturgeon exhibited an average migration rate of 0.34 ft/s (range: 0.01 – 0.78 ft/s) (Table 6). For the 24 sturgeon migrating up to south Montgomery Island from downstream areas, seven fish had sufficient detections from McIntosh Landing to south Montgomery Island (i.e., through "natural" riffles) to provide migration rates (average of 0.29 ft/s; range: 0.07 – 0.84 ft/s). No sturgeon were detected migrating up into the oxbow outlet channel.

Table 6. Migration results for 12 green sturgeon caught upstream of the GCID gradient facility and released downstream near McIntosh Landing in 2006.										
Tag #	**Last Detection at McIntosh Landing**	**1st Detection at South Montgomery Island**	**Elapsed Time McIntosh Landing to South Montgomery Island**	**Migration Rate (ft/sec)**	**Last Detection at South Montgomery Island**	**1st Detection at North Montgomery Island**	**Elapsed Time South Montgomery Island to North**	**Migration Rate (ft/sec)**	**Gianella Flow (cfs) on Day of Passage**	**Gianella Flow + Pump Flow (cfs) on Day of Passage**
220					7/4/06 @ 0:54:47	7/4/06 @ 3:37:20	2:42:33	0.48	11,461	14,183
221					6/30/06 0:50:54	6/30/06 @ 2:31:14	1:40:20	0.78	11,671	14,352
228	7/23/06 @ 0:43:48	7/24/06 @ 4:15:38	27:31:50	0.09	7/25/06 @ 5:15:59	7/28/06 @ 8:02:17	74:46:18	0.02	12,363 (7/25/06) 12,111 (7/28/06)	14,863 (7/25/06) 14,511 (7/28/06)
230	7/17/06 @ 16:08:38	7/19/06 @ 8:21:04	40:12:26	0.06	7/19/06 @ 10:20:43	7/20/06 @ 14:49:02	28:28:19	0.05	12,072 (7/19/06) 12,152 (7/20/06)	14,582 (7/29/06) 14,702 (7/20/06)
232					7/18/06 @ 14:53:43	7/18/06 @ 16:34:03	1:40:20	0.78	11,859	14,359
233	7/19/06 @ 5:14:26	7/19/06 @ 14:35:12	9:20:46	0.27	7/19/06 @ 20:48:17	7/30/06 @ 5:51:35	249:03:18	0.01	12,072 (7/19/06) 12,160 (7/30/06	14,582 (7/29/06) 14,560 (7/30/06)
235					7/22/06 @ 12:18:31	7/22/06 @ 17:05:10	4:46:39	0.27	12,320	14,870
237					7/25/06 @ 9:54:30	7/25/06 @ 12:11:11	2:16:41	0.58	12,363	14,863
239	8/6/06 @ 0:57:26	8/6/06 @ 5:44:53	4:47:27	0.53	8/6/06 @ 13:30:41	8/7/06 @ 0:12:24	10:41:43	0.12	11,798 (8/6/06) 11,712 (8/7/06)	14,048 (8/6/06) 13,962 (8/7/06)
243 (a)	8/14/06 @ 14:27:59	8/16/06 @ 2:26:43	35:58:44	0.07						

Table 6. Migration results for 12 green sturgeon caught upstream of the GCID gradient facility and released downstream near McIntosh Landing in 2006.

Tag #	Last Detection at McIntosh Landing	1st Detection at South Montgomery Island	Elapsed Time McIntosh Landing to South Montgomery Island	Migration Rate (ft/sec)	Last Detection at South Montgomery Island	1st Detection at North Montgomery Island	Elapsed Time South Montgomery Island to North	Migration Rate (ft/sec)	Gianella Flow (cfs) on Day of Passage	Gianella Flow + Pump Flow (cfs) on Day of Passage
246 (a)	8/26/06 @ 4:34:13	8/26/06 @ 18:13:52	13:39:39	0.19						
40 (a)	10/31/06 @ 22:30:34	11/1/06 @ 1:32:35	3:02:01	0.84						

(a) – Fish migrated up to gradient facility, but did not pass.
28 sturgeon detected at McIntosh Landing and/or Pine Creek only.
10 sturgeon migrated up to south Montgomery Island area, but no detections at McIntosh Landing.
1 sturgeon migrated up to gradient facility (did not pass), but no detections at McIntosh Landing and south Montgomery Island.
1 sturgeon migrated past gradient facility, but no downstream detections.
3 sturgeon were not detected on any GCID receiver.

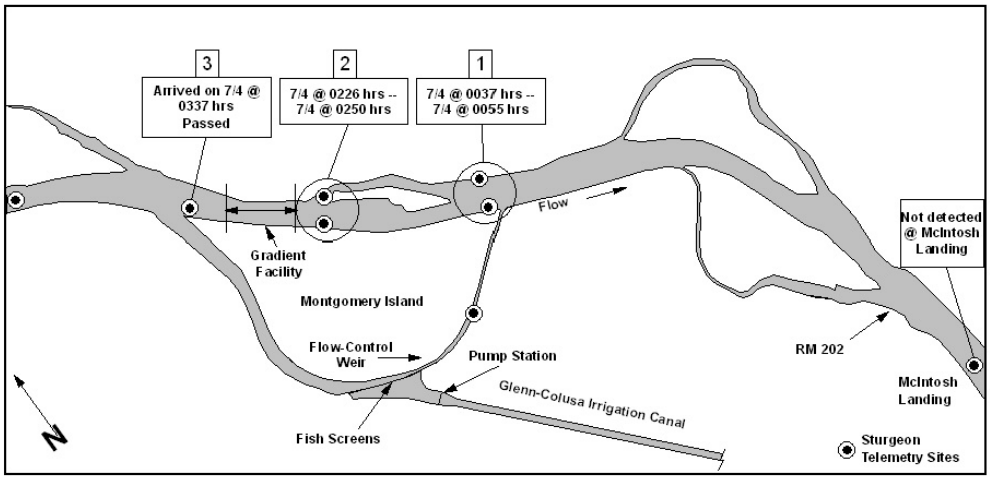

Figure 27. Telemetry data for acoustic-tagged sturgeon no. 220.

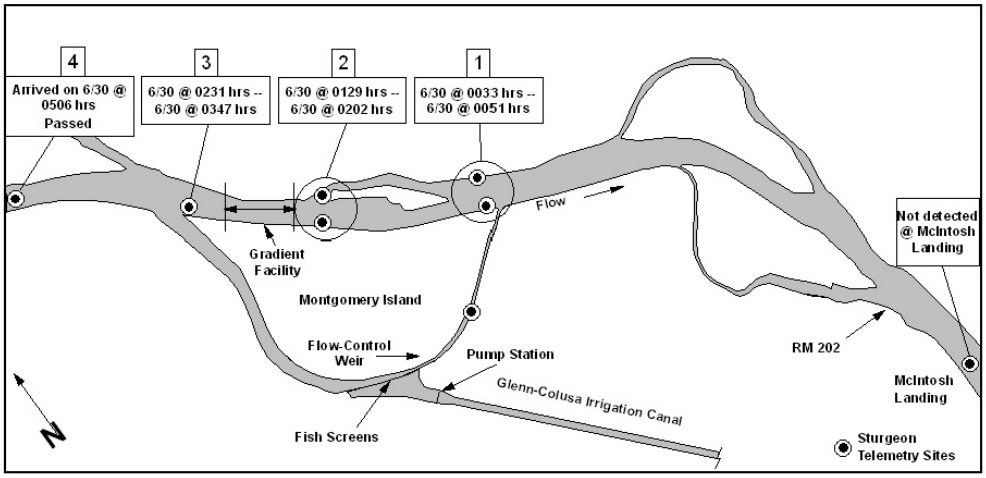

Figure 28. Telemetry data for acoustic-tagged sturgeon no. 221.

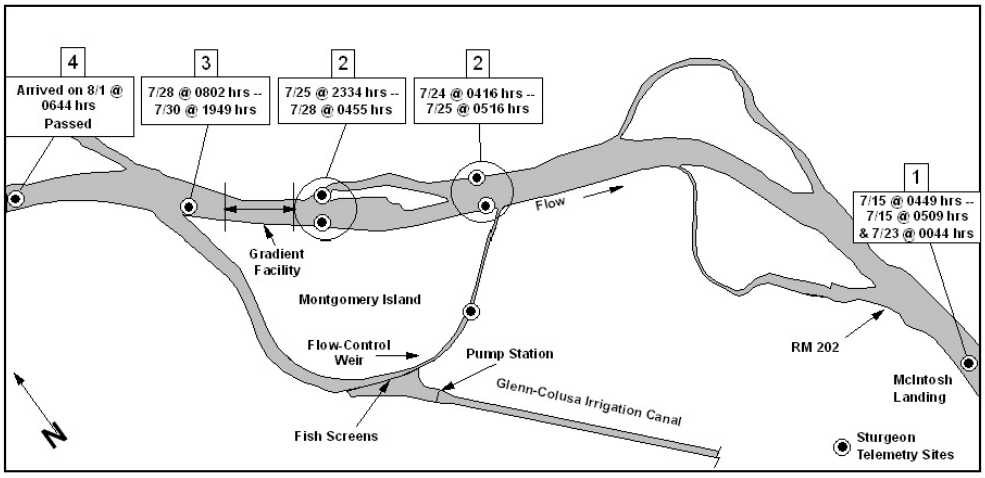

Figure 29. Telemetry data for acoustic-tagged sturgeon no. 228.

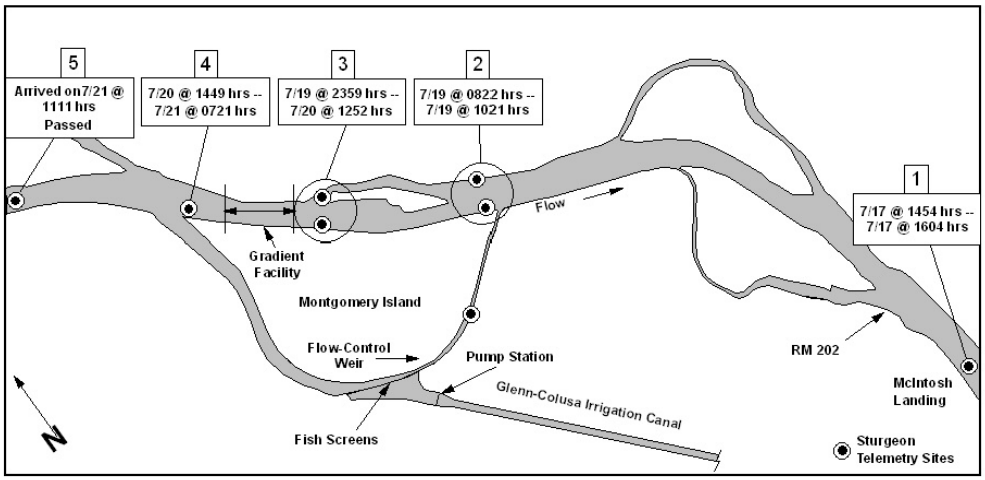

Figure 30. Telemetry data for acoustic-tagged sturgeon no. 230.

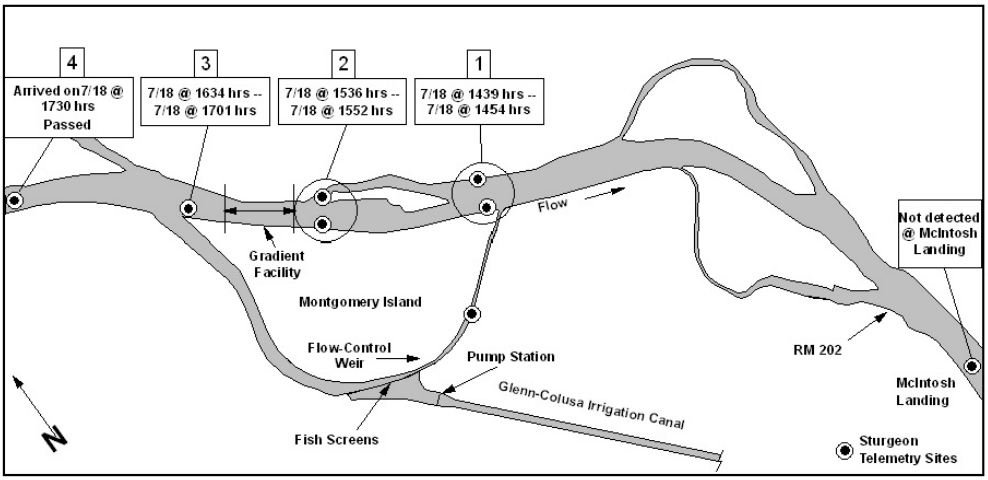

Figure 31. Telemetry data for acoustic-tagged sturgeon no. 232.

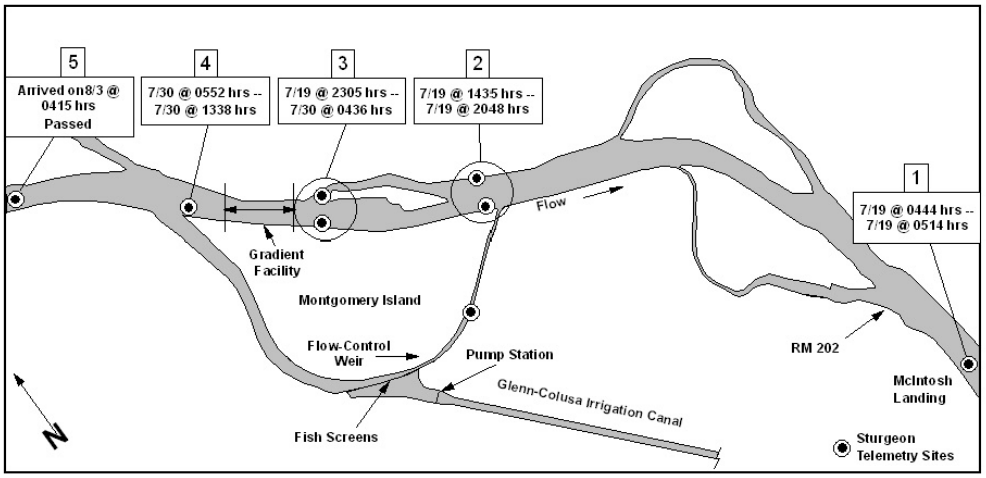

Figure 32. Telemetry data for acoustic-tagged sturgeon no. 233.

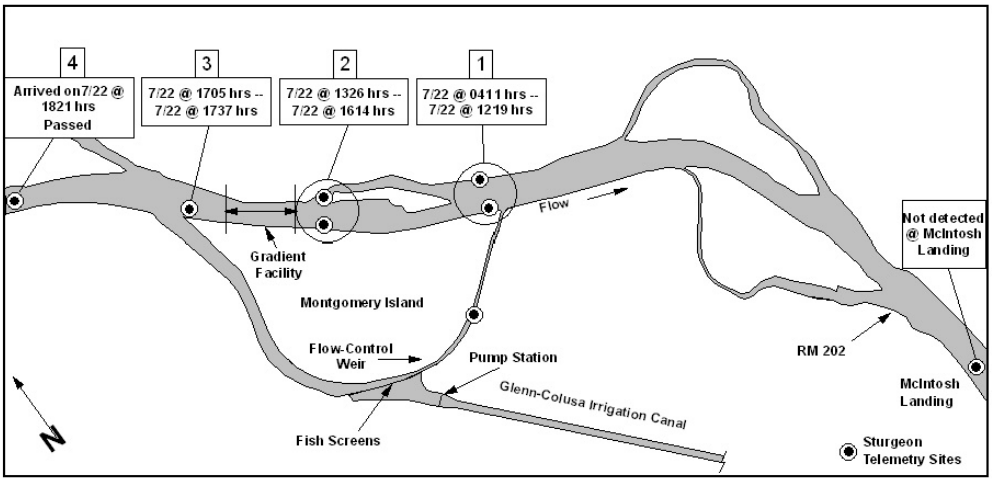

Figure 33. Telemetry data for acoustic-tagged sturgeon no. 235.

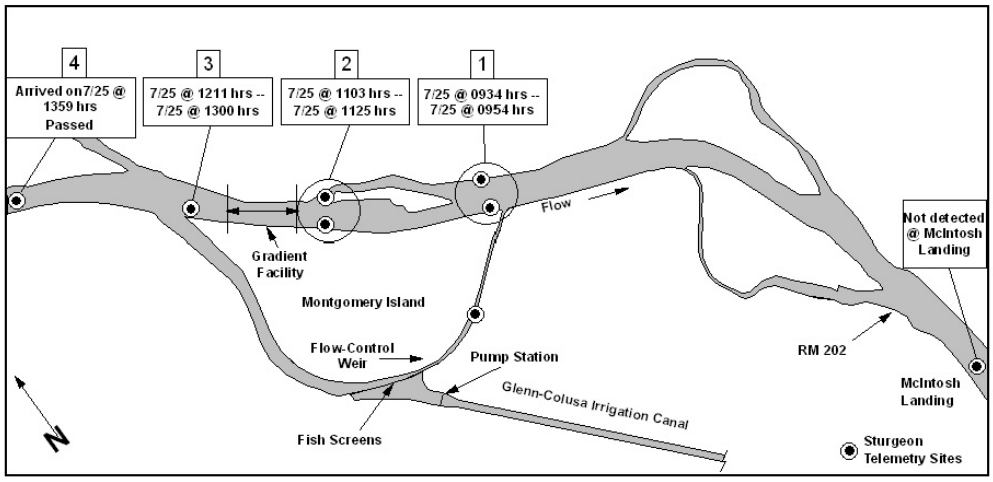

Figure 34. Telemetry data for acoustic-tagged sturgeon no. 237.

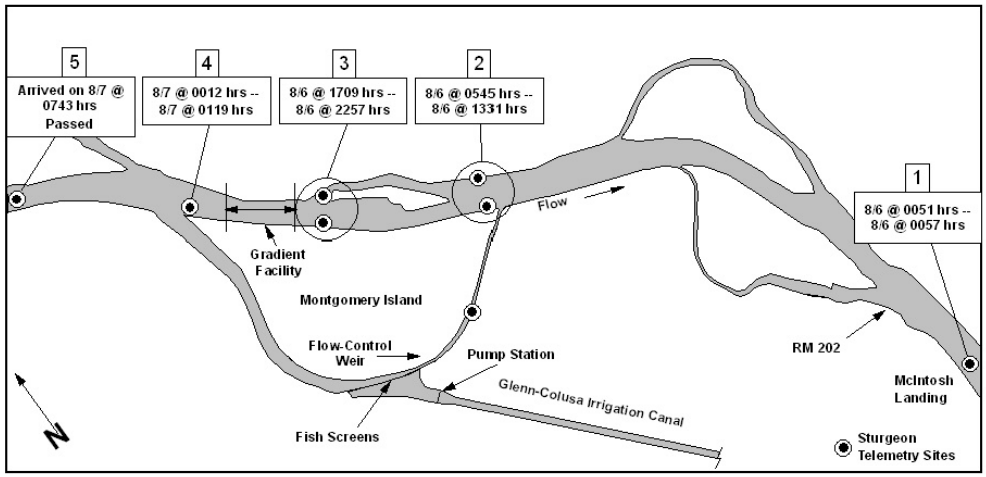

Figure 35. Telemetry data for acoustic-tagged sturgeon no. 239.

The average migration rates and range in migration rates were similar through the "natural" riffles and from south to north Montgomery Island. After the gradient facility was constructed, a large depression in the riverbed exceeding 20 feet in depth formed just downstream of the site (Figures 36 and 37). The presence of this deep hole complicates analyses of the potential effect of the gradient facility on sturgeon migration. For example, if sturgeon prefer this type of holding habitat, the fish may not be induced to migrate any further upstream past the gradient facility. Additionally, temporary holding of sturgeon in this pool to rest for extended periods would account for average slow migration rates. Data collected indicated that some sturgeon did reside for long periods in this pool and deep areas near the oxbow outlet channel. Also, the time of year when fish were tagged and released may have had a confounding affect on upstream migration behavior (discussed below) because most fish were tagged at the end of or after the normal spawning period.

Sturgeon holding in the deep pool upstream of the gradient may have been exhibiting an "aggregation" behavior during summer and fall (Heublein 2006). Aggregation of green sturgeon during the summer has also been reported in the Rogue and Klamath Rivers (Erickson et al. 2002, Benson et al. 2006, as cited by Hublein 2006). The handling stress of tagging and release also may have disrupted normal behavior after release. Many of the sturgeon tagged in this study were detected migrating past the Golden Gate Bridge during the winter (Steve Lindley, National Marine Fisheries Service, personal communication), which was consistent with other ongoing green sturgeon studies (e.g., Heublein 2006).

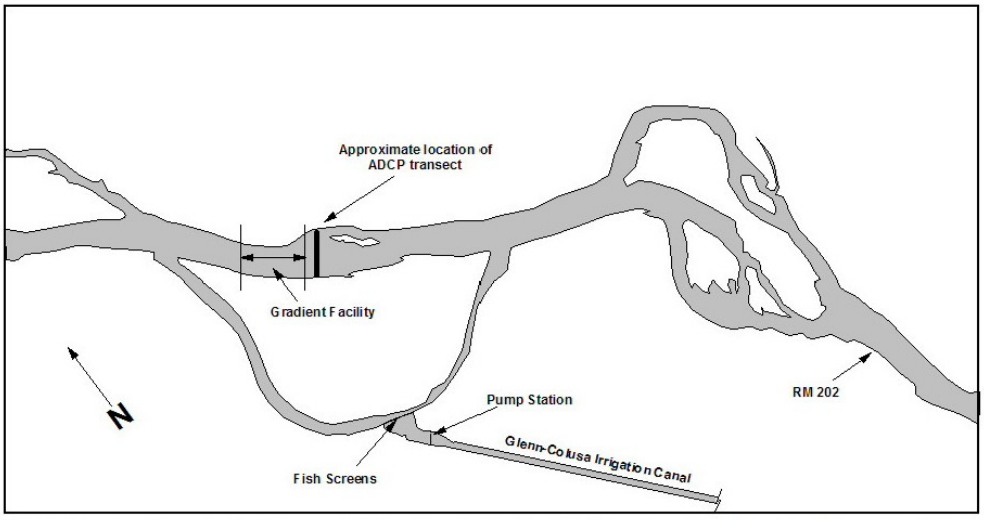

Figure 36 Sacramento River near the GCID pump station showing approximate location of an Acoustic Doppler Current Profiler transect just downstream of the gradient facility on July 25, 2003.

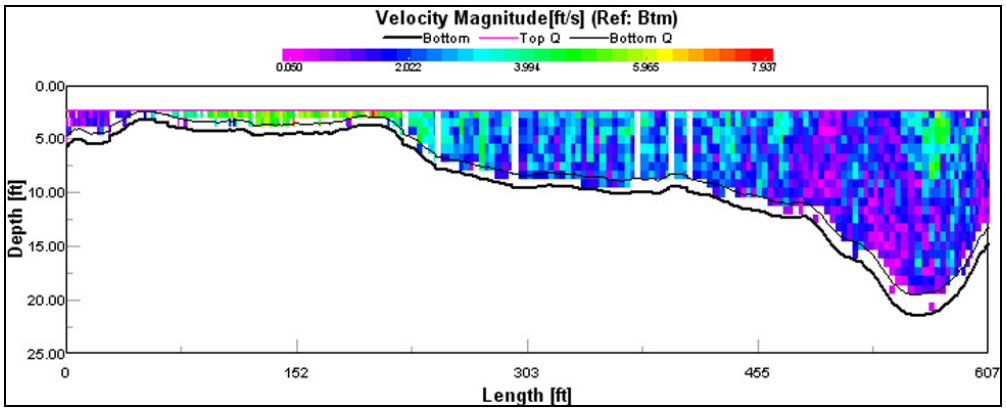

Figure 37. Depths and velocities at the ADCP transect (facing downstream) shown in Figure 36.

During September and October 2007, a DIDSON camera was used to examine the area upstream of the gradient facility where adult green sturgeon were captured to estimate the abundance of sturgeon and determine characteristics of the channel. Additionally, an underwater video camera was lowered to the riverbed to determine the substrate. High concentrations of adult sturgeon were observed with the sonar camera (Figures 38 and 39). Based on sonar imaging, it was estimated that approximately 100 adult sturgeon were present during the surveys. The sonar camera could not determine the species, but it was assumed the majority of the fish were green sturgeon, based on prior angling captures at the site. Also, the underwater video camera revealed the image of a green sturgeon (Figure 40). Based on camera footage, the riverbed was primarily composed of sand with small pockets of gravel and cobbles mixed within the sand. An ADCP cross-sectional profile of the site showed that the near-bed water velocities were relatively high (approximately 1 – 2 feet/s) (Figure 41).

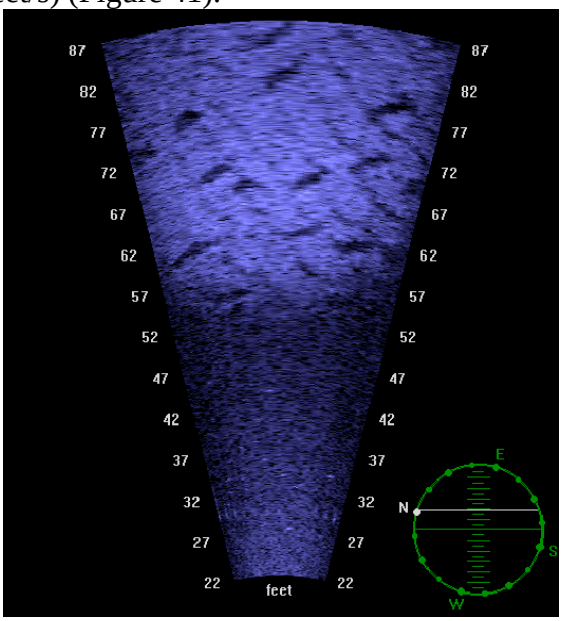

Figure 38. Sonar camera image of approximately one dozen adult sturgeon a short distance upstream of the GCID gradient facility. Most fish are oriented into the current (flowing from lower left to upper right in the image. Undulations in the sand riverbed are evident. Water depth is 27 feet.

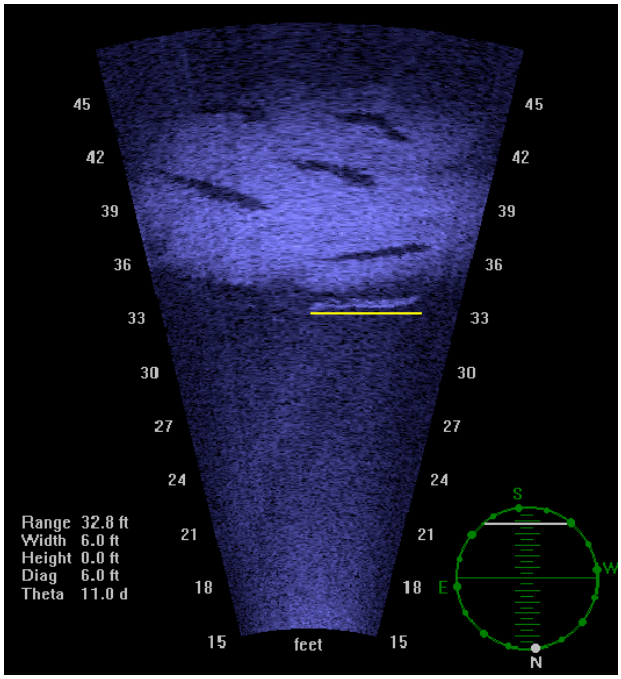

Figure 39. Sonar camera image of five adult sturgeon a short distance upstream of the GCID gradient facility. The sturgeon located 33 feet from the camera lens is approximately 6-feet long (shown by horizontal yellow bar) and positioned a short distance off the bottom as evidenced by its acoustic shadow 36 feet from the camera lens. The other four sturgeon are positioned on the sand riverbed. Water depth is 27 feet.

Figure 40. Adult green sturgeon on the bottom of the Sacramento River a short distance upstream of the GCID gradient facility. Picture taken on the riverbed in 27-foot water depth.

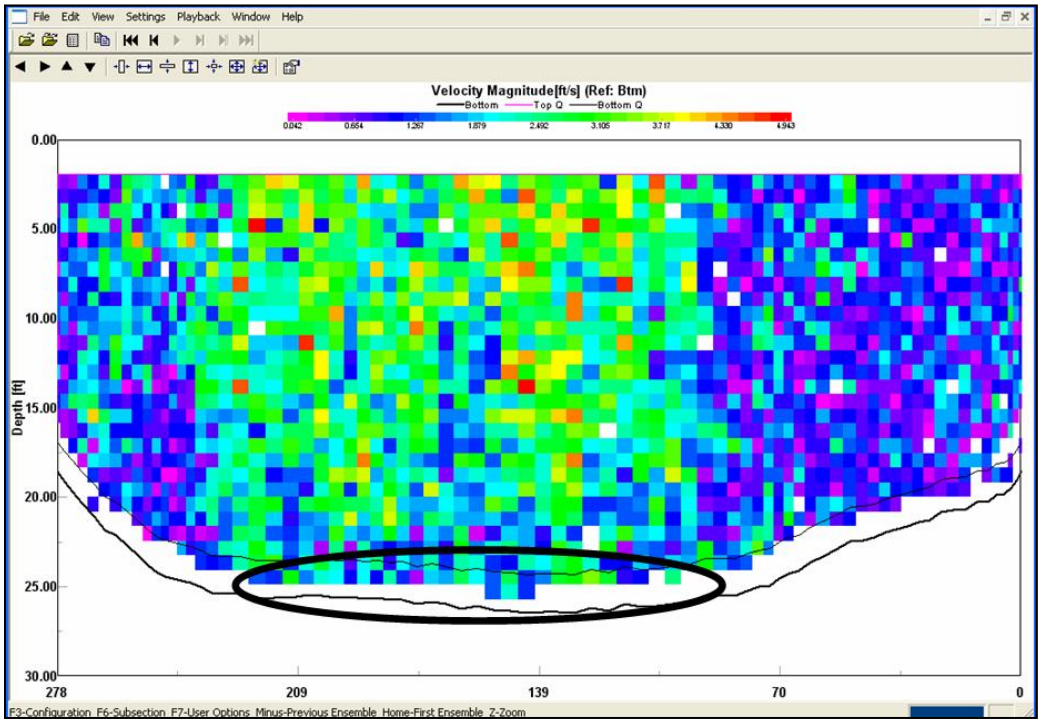

Figure 41. Cross-sectional ADCP profile of water velocity distribution in the river channel a short distance upstream of the GCID gradient facility where abundant green sturgeon were found. Black oval shows location where most sturgeon were observed. Transect measured on August 28, 2007 during a river flow of approximately 9,450 cfs.

Very little is known about the swimming performance of green sturgeon. The *Fisheries Handbook of Engineering Requirements and Biological Criteria* by Bell (1991) provides information on the relative swimming speeds of numerous fish species, but not for sturgeon. The swimming performance of sturgeon is believed to be dissimilar or less than other fish species (Anderson et al. 2004). For example, Peake et al. (1997) found that swimming performance of lake sturgeon (*Acipenser fulvescens*) is inferior to most salmonids. Most recent research on a variety of sturgeon species has focused on swimming behavior in experimental laboratory flumes.

The swimming behavior of adult shovelnose sturgeon (*Scaphirhynchus platorynchus*) from the Yellowstone River was evaluated in experimental fishways at the U.S. Bureau of Reclamation Water Resources Laboratory in Denver, Colorado. Among the types of fishways evaluated, a 70-ft-long rock fishway was more reflective of a riverine environment and potentially applicable to the gradient facility. They found that shovelnose sturgeon swam through gaps between boulders where water velocities were 4 ft/s but only 15 of 24 fish (62.5%) successfully negotiated the fishway (White and Mefford 2002). However, the relevance of that smaller species (~2 - 3 ft long) compared to the much-larger (~5 - 7 ft long) adult green and white sturgeon is unknown.

Because of the concern over potential effects of future water-control structures on adult sturgeon in the Sacramento – San Joaquin Delta and lower Sacramento River, the University of California – Davis conducted studies on adult white sturgeon in an experimental flume to evaluate behavioral responses to various baffles and velocities. The experimental aluminum flume was 80-ft long by 7-ft wide by 5-ft high. The research probably has little relevance to the gradient facility because of the significant differences in the riverine and laboratory conditions. However, preliminary results from that research demonstrated that adult sturgeon migrated past baffles in the flume with swimming bursts when point velocities were as high as 8.27 ft/s (Anderson et al. 2004). They suggested that appropriate white sturgeon passage facilities will probably incorporate high-velocity (e.g., 2.76 - 8.27 ft/s) sections between slower velocity (e.g., 1.67 – 2.23 ft/s) sections for resting areas (Weber et al. 2004). Proposed future research on sturgeon swimming performance to measure endurance (Anderson et al. 2004) may provide information relevant to the gradient facility. At the present time, there is a lack of information on green sturgeon swimming endurance and natural migratory behavior.

Measurements of the hydraulic parameters of depth and velocity at the gradient site and natural riffles indicate that the facility is performing similarly to a natural riffle (e.g., riffle at RM 202.5) (Iceman 2004). Those data would suggest that the gradient facility may not adversely affect upstream fish passage. Based on laboratory studies, it appears that sturgeon can negotiate high water velocities through short cross sections with burst swimming and resting periods. However, the gradient facility is much longer than laboratory flumes and fish must swim in a longitudinal direction through a wide variety of hydraulic conditions that cannot be replicated in an artificial flume.

The highly protracted presence of green sturgeon upstream of the GCID gradient site was considered unusual based on limited information available for the species. The general life history of Sacramento River green sturgeon is assumed to be similar to Klamath River green sturgeon (Moyle 2002). The species is primarily marine and return to freshwater mainly to spawn during March to July, peaking from mid-April to mid-June (Moyle 2002). Fourteen green sturgeon were captured from mid-July to early November in 2003, after the presumed peak spawning period (Table 1). The capture of 40 green sturgeon for the 2005 study also all occurred after the peak spawning period. The fish were caught each month from July into November 2005 (five months) (Table 3). The capture of 54 green sturgeon in 2006 occurred from mid-June through October (Table 5). Three of the green sturgeon captured in mid-July 2006 were full of eggs suggesting that some sturgeon may spawn just upstream of the gradient facility and that the species may spawn later than assumed. Water temperatures in this region (Turek 1990) are within the range considered suitable for sturgeon spawning. The discovery of high aggregations of green sturgeon at this site was inadvertent; other areas may exist for spawning and/or holding. The sturgeon remained for longer periods in freshwater after spawning than previously surmised.

The time of year when sturgeon were tagged may have had an affect on their upstream migratory tendencies. However, the acoustic-tagged green sturgeon that migrated back

upstream to south Montgomery Island and sturgeon that migrated through the gradient site did so after the presumed spawning period. For example, in 2003, the upstream migration from the release site primarily occurred in July and August with one fish in September. In 2005, the upstream migration from the release site primarily occurred in August with one fish in September. In 2006, upstream migration primarily occurred in July and August with one fish in October. Fish tagged and released later in the season may not have had upstream migratory tendencies. If fish had been captured, tagged, and released earlier in the season during their primary spawning migration season, results probably would have been different.

Although sample sizes were small, there was no correlation evident between size of fish and upstream migration tendencies. The sturgeon were assumed to be mature individuals because most fish exceeded the minimum size range at maturity of 51.2 – 59.1-inch total length reported by Moyle (2002). Based on green sturgeon growth rates reported in Moyle (2002), the sturgeon captured in this study probably ranged in age from 20 years to more than 40 years old, averaging slightly less than 30 years old.

Acknowledgements

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