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# Development of Methods to Monitor Pallid Sturgeon (*Scaphirhynchus albus*) Movement and Habitat Use in the Lower Missouri River

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Project Summary Report
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# DISCLAIMER

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# EXECUTIVE SUMMARY

Pallid sturgeon are extremely rare fish endemic to the Missouri and Mississippi River Ecosystems. The rarity of the species makes traditional population assessment methods ineffective due to the low capture rates and the high cost of sampling. Telemetry offers a cost effective approach for gaining intensive data on fish movement and habitat use. However, use of telemetry in large, turbid, high velocity environments is in its infancy. We conducted a study to evaluate the effectiveness of various instrumentation designs and deployment techniques for use in the Lower Missouri River for large species, such as the pallid sturgeon.

Results indicate that radio-telemetry is currently not applicable for use in these systems with large benthic species or with species that frequently inhabit water depths greater than 2-3 m. Ultrasonic-telemetry equipment however, detected transmitters implanted in pallid sturgeon at a range of up to 1 km with high efficiency. Automated ultrasonic receivers were shown to be an effective tool to reduce time spent manually locating fish, and to monitor rapid movement of fish over long distances. Automated receivers were essential in maintaining contact with implanted sturgeon during extreme high water years because they continue to monitor the river for sturgeon during flood conditions when investigators cannot safely access the river. Unusually high river levels during portions of this study limited the ability of researchers to manually locate fish, however available data suggest that pallid sturgeon are capable of rapidly moving long distances, both up and downstream in the Missouri River.

Pallid sturgeon implanted with ultrasonic transmitters selected sandy areas with intermediate to high water velocities adjacent to the main channel, and avoided off-channel areas devoid of current. Some data suggests the possibility of lengthy seasonal movements indicating that sturgeon respond to environmental variables associated with seasonal changes in physical habitat. Significant movement by these fish also indicates that the species is mobile and able to take advantage of discrete habitat rehabilitation and mitigation projects located at intermediate intervals along the length of the river. Data indicate that sturgeon may respond favorably to modifications to channel morphology that emphasize diversity and spatial heterogeneity of habitat patches and complexity of bottom contour.

# INTRODUCTION

Sturgeon and several other large riverine species endemic to the Missouri River are presently endangered, threatened or in decline due largely to massive alteration of riverine habitat and hydrology (Funk and Robinson 1974). The scale and extent of these anthropogenic changes on the lower Missouri River landscape have presented difficult challenges for resource managers and biologists charged with the restoration and recovery of riverine species (Hesse et al. 1989). One such species, the pallid sturgeon (*Scaphirhynchus albus*) is endemic only to the turbid, swift flowing, main channels of the Missouri and lower Mississippi Rivers (Forbes and Richardson 1905, Bailey and Cross 1954). River modifications have adversely affected the pallid sturgeon by blocking movements to spawning and feeding areas, altering conditions or flows of potential remaining spawning areas and feeding areas, reducing food sources or the ability to obtain food, or otherwise altering conditions for the fish's survival (Keenlyne 1989). The pallid sturgeon is extremely rare (Kallemeyn 1983, Grady et al. 2001). Prior to the initiation of this study, capture of fewer than 30 pallid sturgeon had been recorded in the lower 500 miles of the Missouri River (National Pallid Sturgeon Database, U.S. Fish and Wildlife Service, Bismarck, ND). The pallid sturgeon was listed as a federally endangered species in 1990 (Dryer and Sandvol 1993). Preservation and recovery of the pallid sturgeon is hindered by a general lack of data on the behavior, movement and habitat of the species in large portions of its range.

Traditional studies of the life history and habitat use of fishes has centered on multi-habitat analysis to determine relative preferences across seasons and lifestages. These approaches cannot be used for rare species, however, because they are extremely labor intensive and unlikely to produce sufficient observations to derive meaningful inferences. Telemetry, however, allows intensive studies of individual fish to determine relevant information, such as habitat preference and rates of movement during the annual cycle. Use of telemetry in turbid, rapidly flowing systems such as the Missouri and Mississippi Rivers however, are relatively new due to physical and chemical constraints associated with high concentrations of suspended matter, high conductivity and high background levels of acoustic noise. These exploratory studies are needed to make logistical and practical decisions regarding equipment choice, deployment and operation.

Our objectives were to 1) acquire and test telemetry systems capable of monitoring sturgeon movement in large riverine systems, and 2) apply these capabilities to investigate behavior and movement of pallid sturgeon in the lower Missouri River.

# METHODS

## Development of Telemetry Capabilities for the Lower Missouri River:

For many reasons, previous attempts at employing telemetry and remote sensing technologies in the lower Missouri River have met with only limited success. The environmental and biological constraints that limited earlier studies were identified and considered in the development of a telemetry system for use on the lower Missouri River. An analysis of signal propagation and detection of radio and ultrasonic frequencies was conducted in controlled simulations and field experiments in the Missouri River (Appendix A). Available systems and technologies were evaluated based on utility, cost-effectiveness, and expected reliability of performance under the adverse environmental conditions documented during our engineering analysis.

### Environmental and biological constraints

The lower Missouri River is characterized by high conductivity (often >600 uS) and suspended sediment load (often > 1000 NTU) that dramatically affects telemetry signal propagation, limiting the usefulness of radio frequency transmitters. Field experimentation with 50 and 150 MHz frequencies indicated very poor expected ranges of detection at depths greater than 2-3 m. The pallid sturgeon is primarily a benthic fish and habitats available to this fish in the Missouri River can exceed 10 to 20 m. In addition, the small size of the pallid sturgeon expected to be available for tagging (2-4 kg) and the relatively small body cavity size of this species requires a correspondingly small, lightweight tag. This limits the battery size, reducing output power, and further limiting the detection range of radio transmitters. Current pallid sturgeon handling protocols strongly discourages external antennas for internally implanted radio transmitters. Wire antennas protruding from the body cavity often result in poor healing, irritation, infection and transmitter expulsion. This is especially a concern with benthic fishes that spend a considerable amount of time in contact with the substrate and other debris, which could catch the protruding antenna resulting in continuous irritation and trauma. The alternative is to coil the antenna and encapsulate it inside the transmitter casing. Unfortunately this configuration can be expected to effectively reduce the detection range by half. Given the current constraints and available equipment, radiotelemetry was not a viable solution for monitoring of pallid sturgeon in the lower Missouri River.

The alternative to radio telemetry, is ultrasonic telemetry. The Missouri River's high current velocity (often >2m/s), turbulence, sandy bedload and dramatic fluctuations in river level produce and the USFWS (2000) were also used to guide selection of experimental animals. Questionable specimens were tentatively designated as hybrids. Hatchery personnel selected gravid females and candidate males for propagation purposes and the remaining individuals were implanted with ultrasonic transmitters and released into the Missouri River at river mile 170.5 (table 2). Individuals utilized in the propagation program were allowed to recover then implanted and released at the same location at a later date.

A total of 30 pallid sturgeon were tagged and released over three years. Of these only two were collected from the lower Missouri River. Within that same time period, 10 suspected hybrid sturgeon were implanted with transmitters and released. With the exception of 1995, fish typically were held in laboratory for one day to one week for post-surgical evaluation prior to release. No surgical complications or mortalities were observed. The extreme flood event of 1995 began during the surgical recovery period of 5 of the pallid sturgeon captured that year. Due to the severity of the flooding these fish were held for 5 to 9 months following implantation. All fish healed rapidly with no evidence of transmitter expulsion. All 1995 fish were held in the laboratory until the floodwater had receded regardless of capture date. No evidence of surgical trauma, or transmitter-induced irritation or expulsion was observed in fish held for as long as 9 months.

Automated receivers were deployed at 8 locations covering 240 km from the mouth of the Grand River (river mile 250) to near Hermann, Missouri (river mile 100) (figure 3). Manual tracking efforts were determined in part by the location and movement of the fish. Attempts were made to travel the entire study reach and locate each fish at least twice each month, at a minimum. Locations of fish were recorded using a Trimble Pro-XL sub-meter GPS unit. Temperature, depth and substrate data was recorded for each point location. Current velocity was measured 40 cm below the surface using a Marsh-McBirney, Inc. Flow-mate model 2000 flowmeter. Bathymetric data was collected at a limited number of sites using a high resolution, survey-quality depth sounder with thermal analog recording capabilities (Innerspace Technology, Inc., Model 449DF) operating at 208 kHz. Depth recordings were geo-spatially referenced using NEMA output from the Trimble Pro-XL GPS with real-time correction from a Trimble Pro-Beacon U.S. Coast Guard radiobeacon receiver.

Location data was differentially corrected and transferred to a GIS database (Appendix B). To examine habitat use at a large spatial scale, telemetry point data was combined with the 1994 U.S. Army Corps of Engineers hydrographic survey with contour lines drawn at 6, 9 and 12 feet below the construction reference plane. To highlight stable macrohabitat features, such as sandbars, islands, secondary channels and wing dikes, telemetry and hydrographic survey data were overlain onto DOQ's photographed during low water in March 2000 by U.S. Army Corps of

Engineers contract. Because of the engineered constraints placed on the river, some macrohabitats are relatively stable over time. This permits the combination of the two temporally disjunct datasets to illustrate gross habitat features in the general area of each point location. The 1995 DOQ photo set could be substituted (available from the Missouri Spatial Data Information Service), but many of the photos were taken only during periods of high water and therefore do not highlight persistent habitat features.

## RESULTS

### Effectiveness of Ultrasonic Telemetry:

Manual searching for tagged fish was a slow process. Due to high current velocities and long pulse periods (>2000 ms) the maximum search rate was approximately 10 km/h traveling downstream. Increased speeds dramatically reduced effectiveness. A single boat could typically cover 60 km of river per day. The range of detection using manual tracking equipment averaged 300-500 meters depending on river conditions and stage. Detection range decreased with increasing stage and proximity to flow training structures. However, the uniform channelization of the river to a width of approximately 300 m throughout the study segment, with few or no backwater areas aided search efforts. A single boat traveling down the center of the river provided adequate coverage to reliably detect transmitters. Due to the high background noise, directionality of the hydrophones, and precise gain control the location of individuals could be accurately determined within 2-3 meters.

Automated receivers were placed at approximately 40-km intervals along a 240-km mile stretch of the lower Missouri River from the mouth of the Grand River to Hermann, MO (figure 3). Effectiveness of these receivers in detecting and identifying passing fish was nearly 100% when placed appropriately. Effectiveness was highly dependent on receiver placement relative to channel morphology and engineered structures that could block signals from transmitters and hide fish from monitoring receivers. The ability to cross check manual locations of fish with approximate locations provided by automated receivers prevented searching entire river segments and provided a measure of search efficiency. Additionally, automated receivers were able to document rapid long-range movements of sturgeon, and continuously monitored fish passage during extended times when field crews were unable to gain river access during extreme high water events. This study occurred during a period of historically high water levels (figures 4, 5, 6 and 7). Some segments of the river were impossible to access for weeks at a time due to high water, inaccessible boat ramps, and large woody debris. While automated receivers continued to work during extreme water events, they were subject to damage by passing woody debris and prone to sediment burial. One receiver was lost, and two were buried by sediment and debris. One of the buried receivers was recovered 3 years after initial deployment.

## Movement and Habitat Use of Sturgeon:

Data from this study must be interpreted with caution. Nearly all the fish used in this study were translocated fish and may have been initially disoriented by capture, transport, extended holding periods and release into unfamiliar surroundings. Nevertheless, the data is useful for examining gross habitat use, and provides insight into the innate propensity of the species to select particular habitat features and provides some limits to the spatial scale at which the species lives. Comparing the data with related ongoing studies with pallid sturgeon in the Missouri and Mississippi Rivers can increase confidence in the results. Suspected hybrid sturgeon were utilized in 1995 primarily to develop and refine procedures and protocols. Observations of suspected hybrids in subsequent years were too few to examine differences between groups and will be omitted from the remainder of the discussion. A total of 397 relocations of 30 pallid sturgeon were made between 1995 and 1998 (Appendix B). The least number of relocations for a single fish was 3 and the greatest number was 39. The median number was 11.

Pallid sturgeon exhibited the ability to travel long distances in relatively short periods. Distances greater than 40 km/day downstream and greater than 25 km/day upstream were recorded. Extreme movements occurred during flow events in spring and late fall. These rapid movements would have been impossible to document without the existence of automated monitoring sites. The study period was marked by long periods of historically high river levels that prevented field crews from searching for fish. Automated receivers continued to monitor fish passage and recorded rapid movements in response to high water events. In most studies these movements would have gone unobserved. Unfortunately manual-tracking data is not available to corroborate movement by all sturgeon in response to these hydrological events and therefore the data are insufficient for anything but anecdotal reference. Some evidence for seasonal movement of sturgeon was also indicated. Sturgeon captured and released in spring showed a strong trend towards upstream movement. Sturgeon released in fall or winter moved downstream. Movements greater than 125 km were observed over a single season. Movements of greater length and duration occurred, but were not recorded because fish left the study area. Of fish that left the study area (either upstream or downstream) only one-third returned within the 14-month life of the transmitter.

During all seasons, pallid sturgeon were found in locations with current. Velocities at location ranged between 0.25 and 1.8 m/sec with a mean slightly greater than 1 m/sec. Sturgeon were almost exclusively found over a sand substrate (>95%)—the predominant substrate type in the lower Missouri River. Depth at location averaged 3 m and ranged from <1 to 10.5 m. Though descriptive measurements such as current velocity and depth can be collected at point locations, their usefulness is suspect due to the dynamic nature of river habitats. Depths can quickly change by several meters and flows can change by an order of magnitude within days. In addition, sturgeon were often found in locations of turbulence or complex current patterns, such as wing dike tips, off sand bars or near steep drop-offs where current velocities could vary by as much as 1.5 m/s between each side of the tracking vessel.

Placing point relocations of sturgeon within a meaningful pre-defined habitat classification system is problematic. For the great majority of the study period high discharges inundated all wing dikes and flow training structures, as well as all sand bars and many islands (figures 4, 5, 6 and 7). Very few visible macrohabitat elements were available to assign to the relocation point or to associate with the presence of the tagged fish. A broader-scale assessment of physical habitat used by pallid sturgeon is needed in which locations are correlated with bottom morphology, areas of habitat diversity or particular physical habitat features. By plotting the relocation of tagged sturgeon against the 1994 hydrographic survey and DOQ's photographed during low water periods it is possible to examine habitat use at a broader, albeit grosser, spatial scale to identify features or conditions that may be important to the fish. For example, sharp changes in bottom relief (drop-offs, shelves, scours), the spacing of engineered flow training structures, and the position of the thalweg appear to have greater influence over sturgeon location than depth, substrate or current velocity (figure 8). Pallid sturgeon were most often located in moderate current velocities at the channel margin or border, on outside bends, near sand islands, and off the ends of wing dikes (figure 9). However, sturgeon were not found in slack water behind wing deflectors and closing structures, or in deep holes and connected scours in the absence of current. Sturgeon also were relocated with far less frequency in narrow straight reaches with closely spaced wing dikes (figure 10). Although not often found within the navigation channel, pallid sturgeon readily moved across and within the main channel area. The high flow velocities of the navigation channel (often > 2m/sec) did not appear to act as a barrier or limit movement by pallid sturgeon.

## APPLICATION AND MANAGEMENT IMPLICATIONS

Ultrasonic telemetry is a viable tool for use in the lower Missouri River. The development of effective capabilities to monitor the behavior and habitat use of riverine fishes in the lower Missouri River will help to provide the information necessary to conserve and manage species of concern. Technological advances in biotelemetry and remote sensing have broad application and enables investigators to address new questions and approach difficult problems with increased likelihood of success. Large riverine systems, like the Missouri River, are difficult to sample using traditional gear and techniques. In these systems telemetry studies are particularly effective in filling critical data gaps. Biotelemetry tools can be used to: 1) document movement and behavior in the field under severe environmental conditions, 2) monitor behavior of organisms in response to changing environmental conditions, 3) focus sampling and monitoring efforts for target species, 4) develop biologically meaningful habitat classification systems, 5) rank and prioritize habitat for preservation or restoration, and 6) guide and evaluate habitat restoration and mitigation efforts.

While much of the data collected in this study must be qualified because of the origin of the sturgeon that were used, there are many striking similarities between the conclusions of this study and others. Results of all other telemetry investigations with pallid sturgeon report that this species prefers sand substrate in relatively swift flowing water. Depth and velocities used by pallid sturgeon varies somewhat with geographic location from the Yellowstone River in Montana (Bramblett and White 2001), to the Platte River in Nebraska (Snook 2001), to the Mississippi River bordering Tennesee (Sheehan et al. 2000), most likely due to different absolute ranges of these variables within the habitats available. However, investigators working in these systems all attempt to convey the realization that the habitat used by the pallid sturgeon is not adequately characterized by point estimates of physical variables. Descriptors often used by investigators to categorize habitats frequented by pallid sturgeon include "diverse", "complex" or even "unique". From the perspective of a single point in space, these descriptors are difficult to quantify. However, within a larger spatial perspective, these habitats can be described, characterized and modeled in sufficient detail to guide rehabilitation efforts. For example, telemetry data in the present study clearly indicate that pallid sturgeon are often associated with sand bars as indicated by aerial photography and bathymetry. This may lead to the overgeneralization that adult pallid sturgeon prefer shallow water habitat. More observations of sufficient detail within the larger spatial context will likely indicate that bottom morphology or the spatial arrangement of shallow water and deep water, not absolute water depth, may be most important to adult pallid sturgeon. Where and how habitat is engineered or rehabilitated is likely just as important as what is built.

The present study provides additional evidence that physical habitat rehabilitation and modification of river channel morphology would benefit adult pallid sturgeon. While physical design criteria are difficult to derive from limited data sets such as these, it appears likely that pallid sturgeon would respond favorably to engineering design changes on multiple spatial scales. The rapid movement of individual fish indicates that this species can take advantage of relatively small and widely spaced rehabilitation and mitigation projects. When designing modifications to benefit adult sturgeon particular emphasis should be placed on increasing complexity of channel bedform, maximizing spatial heterogeneity of habitat patches (emphasizing patterns of bottom relief rather than total acres of a particular depth) and providing diversity of flow through and around habitat patches. With additional study measures of suitability could be derived and predictive models of habitat quantity and quality could be constructed and validated.

Understandably the data set discussed in this report has several important limitations. The reproductive status and motivational state of the fish examined during this study was unknown. While this limitation was exacerbated by the use of translocated fish that were released into an unfamiliar landscape, all telemetry studies conducted with pallid sturgeon to date are similarly restricted by the inability of the investigators to relate habitat use to the relative importance of the habitat for the fulfillment of specific life requirements (e.g., feeding or spawning). Additional studies that combine telemetry and remote sensing data with traditional sampling approaches are necessary to develop models that can truly assess the value of habitat to particular life stages of this species. Most habitat rehabilitation and mitigation efforts on the Lower Missouri River will occur at relatively small, discrete locations and will necessitate fairly rigorous engineering and control criteria to maintain the multitude of uses on the river. With limited resources and opportunities it is desirable to be able to develop habitat projects for the maximal benefit to the target species.

Secondly, as is the case with any rare or endangered species, management entities are required to focus intensive efforts towards the recovery of that species. While this limited data set provides some guidance, management agencies must bear in mind that this study only examines habitat use by adult fish and does not describe habitat needed by other life stages. In addition, care must be taken not to disregard the habitat in which pallid sturgeon are not found (e.g., backwater areas, off-channel scours) or to dismiss these areas as inconsequential. Although adult pallid sturgeon are obligate rheophiles that require sand substrate and current, other habitat types likely contribute significantly to the pallid sturgeon's life requirements (e.g., food sources, hydrologic patterns, and water quality).

Combining movement and habitat use data with hydrographic remote sensing and hydraulic models allows researchers and managers to obtain information about the fish's behavior and habitat requirements in the context of the larger surrounding environment--information that is not available when collecting only habitat information at the point of location. Aside from being a valuable visualization tool, hydrographic and bathymetric data can be incorporated into biologically based classification systems and spatial models. Bringing these technologies together will facilitate the identification and characterization of key habitat features that may be limiting. In dynamic systems these key physical features may be difficult to identify and characterize, as their availability and use often change with river level and season. The resulting spatial habitat models will provide powerful and cost-effective tools to examine and quantify changes in physical habitat features and their use by aquatic organisms (figure 11).

## ACKNOWLEDGEMENTS

The Missouri Department of Conservation provided assistance in obtaining pallid sturgeon for this study. The assistance and support of the U.S. Fish and Wildlife Service and the Missouri Cooperative Fish and Wildlife Research Unit is gratefully acknowledged. A. Banks, E. Brunson, R. Calfee, N. Giovanini, R. Skinker, J. Whitaker, and A. Zaga assisted with the collection of telemetry data. Telemetry constraint analyses were conducted with the assistance of Cam Grant of Grant Systems Engineering, Inc,

**Figure 1.** Ultrasonic pingers implanted into sturgeon measured 90 mm in length and 16 mm in diameter. Source strength was 153 db re 1μPa at 1m and estimated life was 14 months. External attachment points were removed and the ends of the tag rounded prior to implantation.

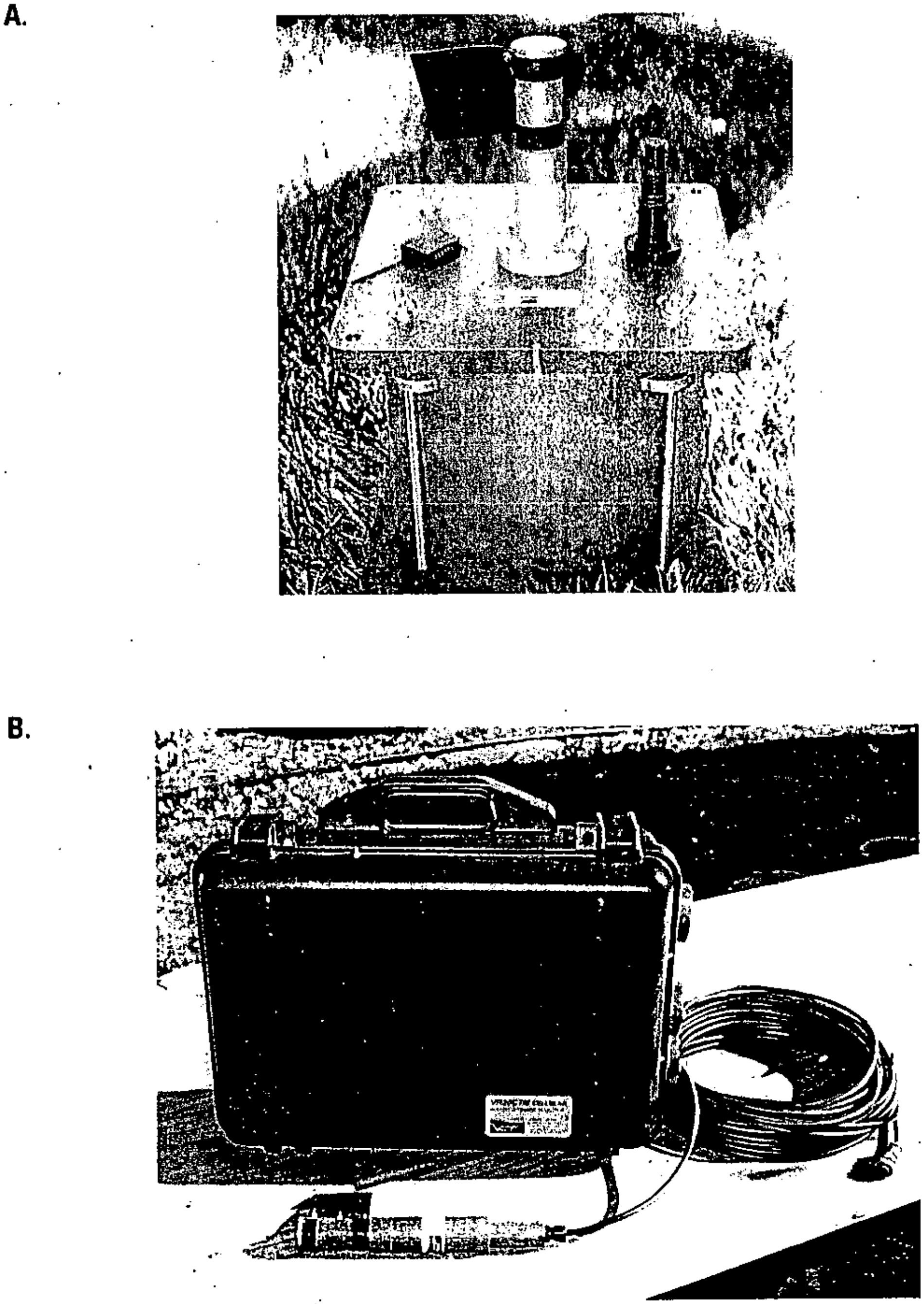

**Figure 2.** Automated monitoring receivers deployed in the Missouri River included; (A) six self-contained, submersible receivers with serial download capability and (B) two weatherproof receivers with external submersible hydrophones and cellular data communication capability.

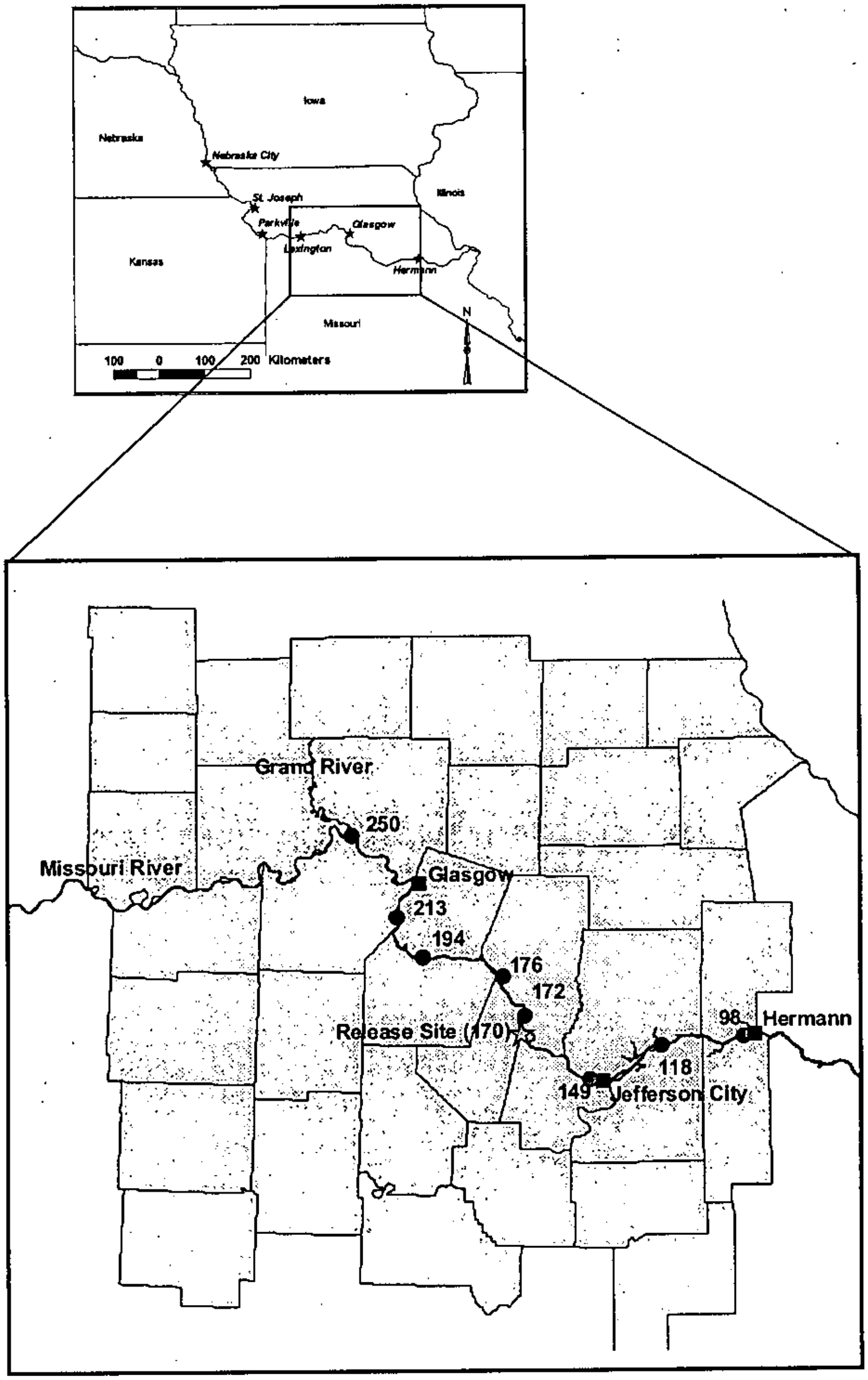

**Figure 3.** Map of the Missouri River including the study reach from the mouth of the Grand River to Hermann, Missouri. Automated monitoring receivers were deployed at locations indicated by the filled circles (●). All implanted fish were released at river mile 170 (★). Municipalities (■) are added for reference.

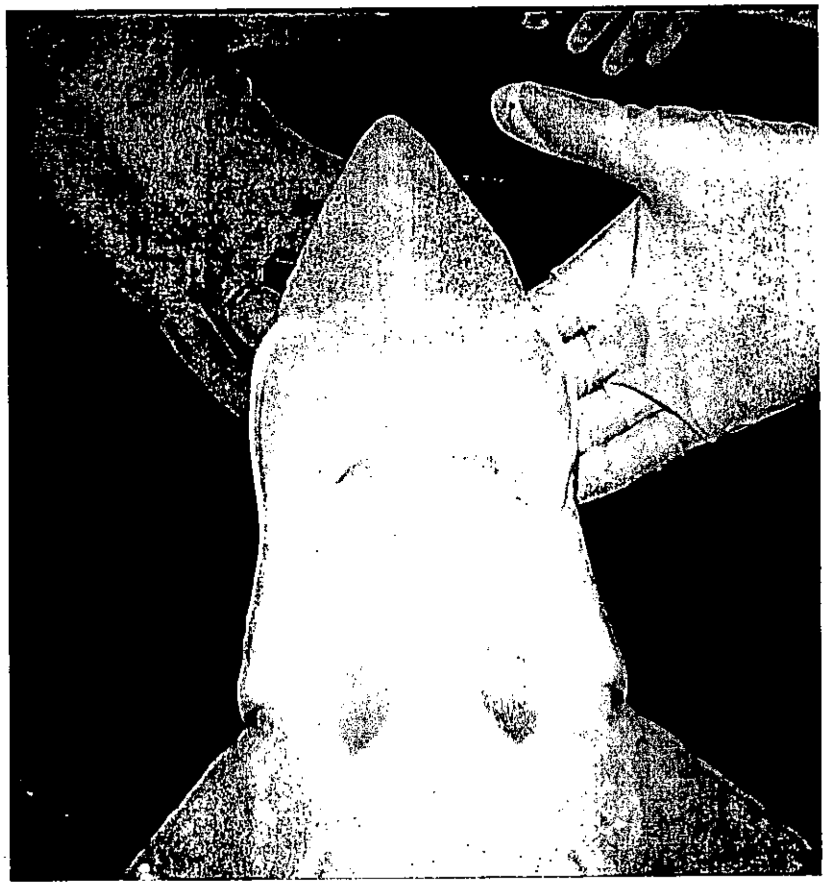

**Figure 4.** Pallid sturgeon were identified using characteristics described by Bailey and Cross (1954). Morphometric indices developed by Keenlyne et al. (1994) and the USFWS (2000) were also used to guide selection of experimental animals. Questionable specimens were tentatively designated as hybrids.

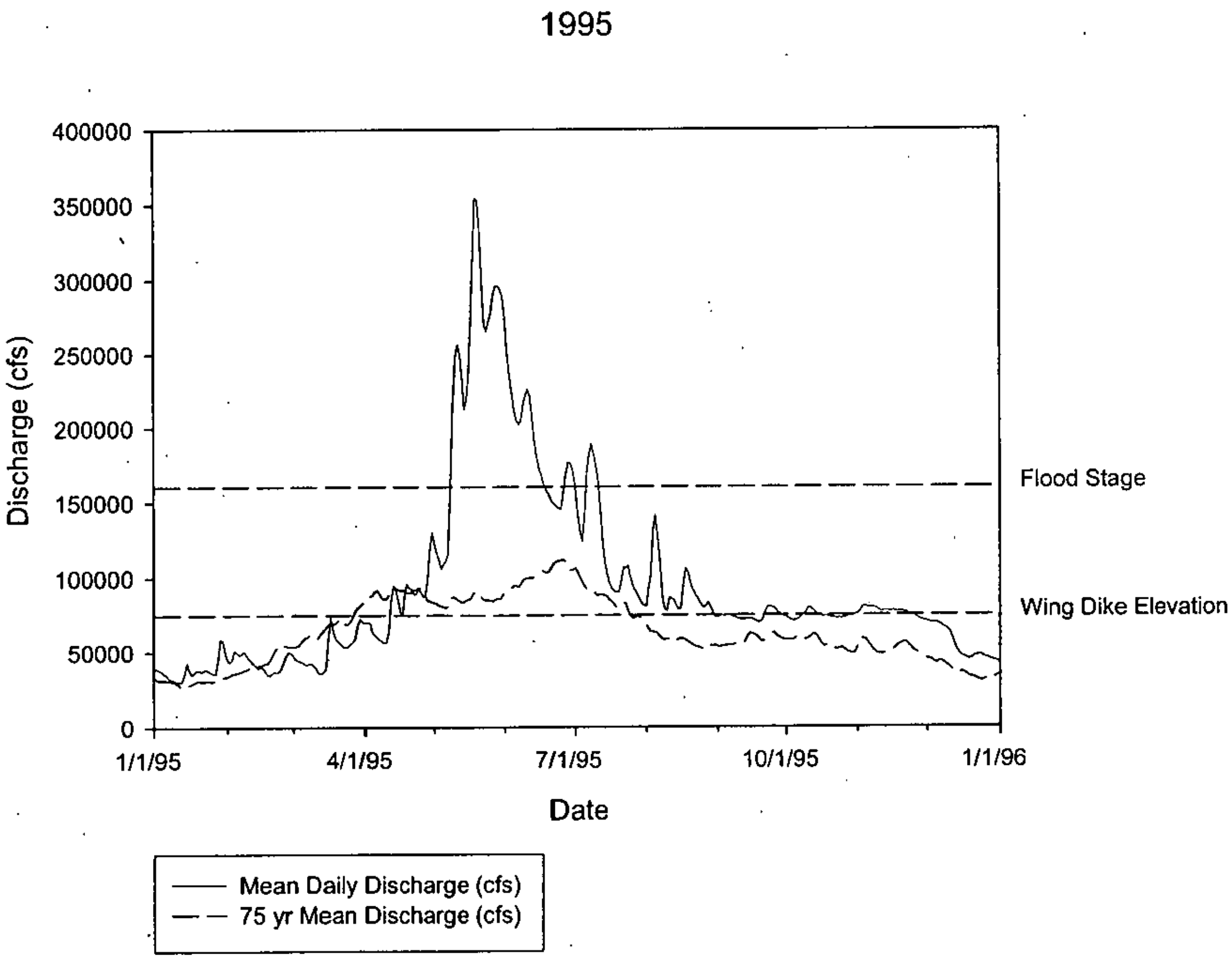

**Figure 5.** Mean daily discharge recorded from January 1, 1995 to January 1, 1996, for the Missouri River at Boonville, Missouri. The 75-year mean daily discharge is plotted for comparison. Horizontal reference lines indicate approximate discharges at which wing dikes are over-topped and flood stage is exceeded.

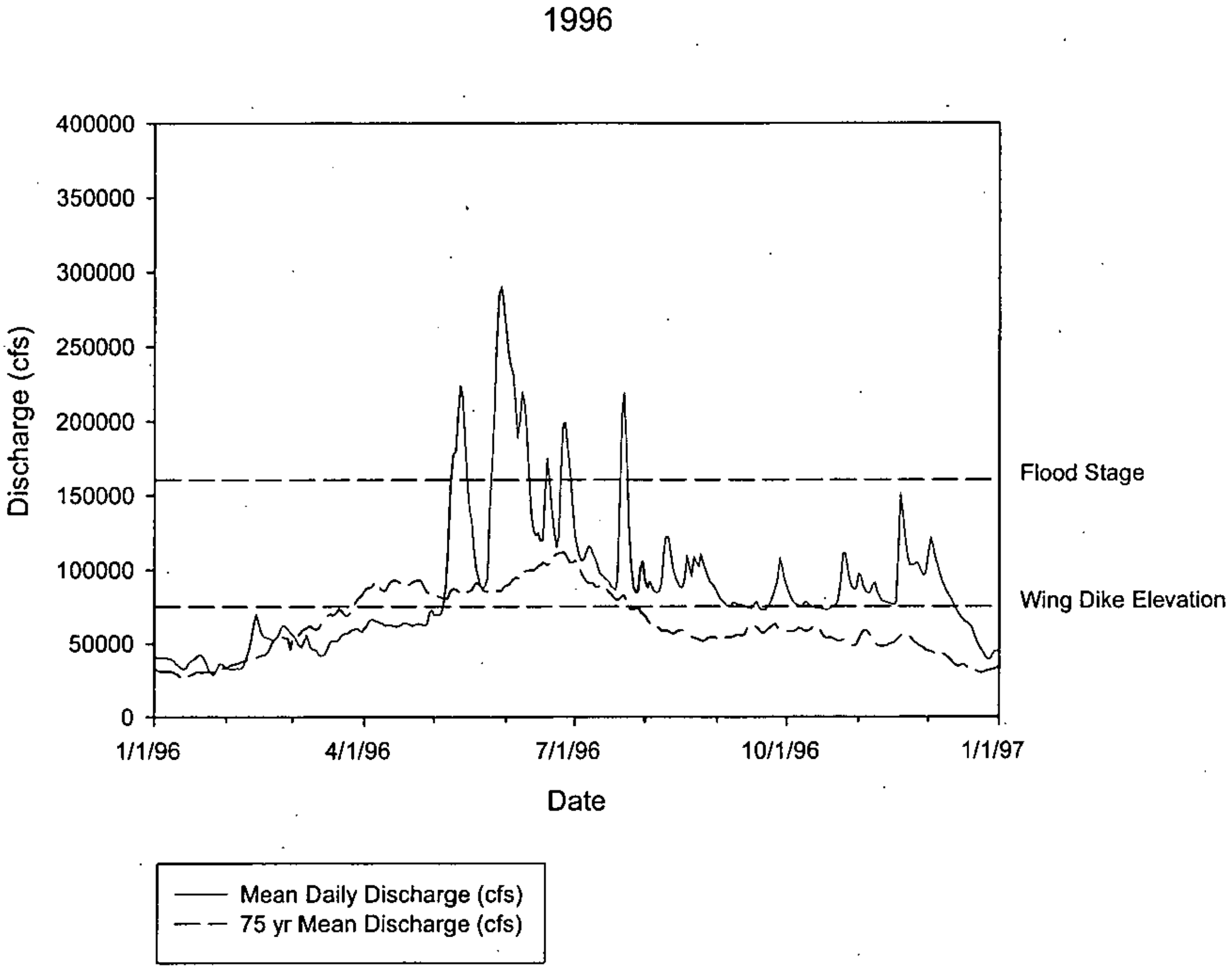

**Figure 6.** Mean daily discharge recorded from January 1, 1996 to January 1, 1997, for the Missouri River at Boonville, Missouri. The 75-year mean daily discharge is plotted for comparison. Horizontal reference lines indicate approximate discharges at which wing dikes are over-topped and flood stage is exceeded.

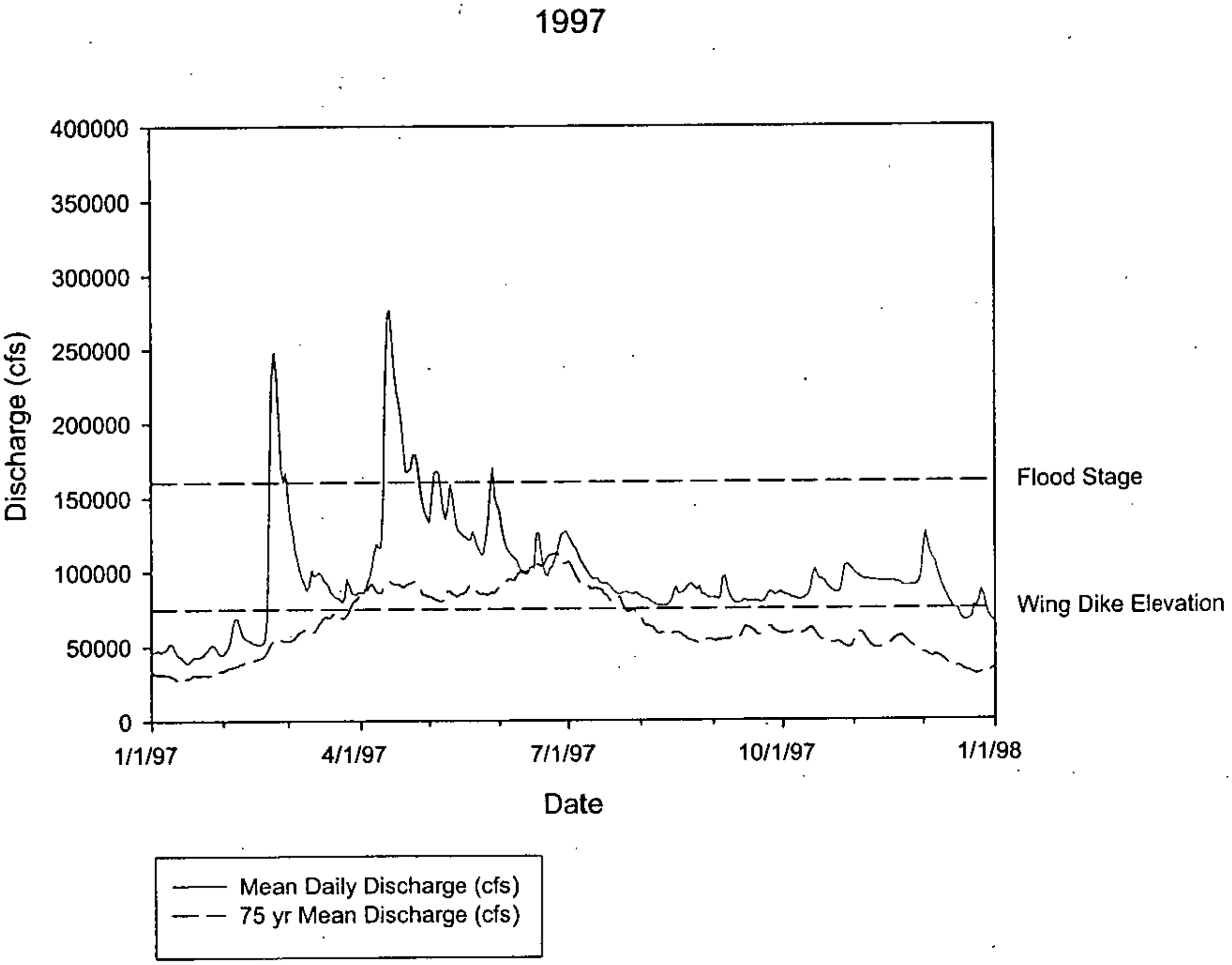

**Figure 7.** Mean daily discharge recorded from January 1, 1997 to January 1, 1998, for the Missouri River at Boonville, Missouri. The 75-year mean daily discharge is plotted for comparison. Horizontal reference lines indicate approximate discharges at which wing dikes are over-topped and flood stage is exceeded.

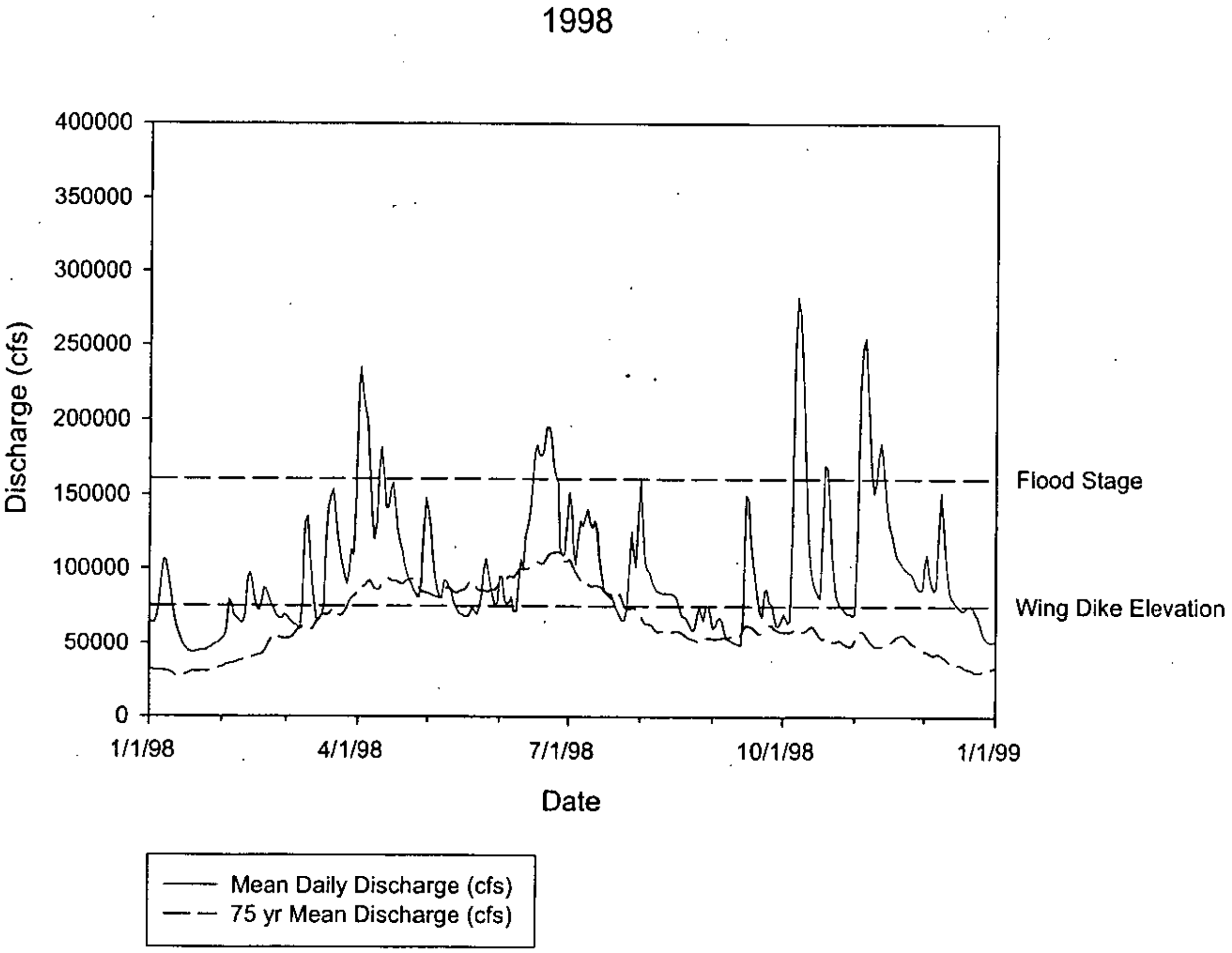

**Figure 8.** Mean daily discharge recorded from January 1, 1998 to January 1, 1999, for the Missouri River at Boonville, Missouri. The 75-year mean daily discharge is plotted for comparison. Horizontal reference lines indicate approximate discharges at which wing dikes are over-topped and flood stage is exceeded.

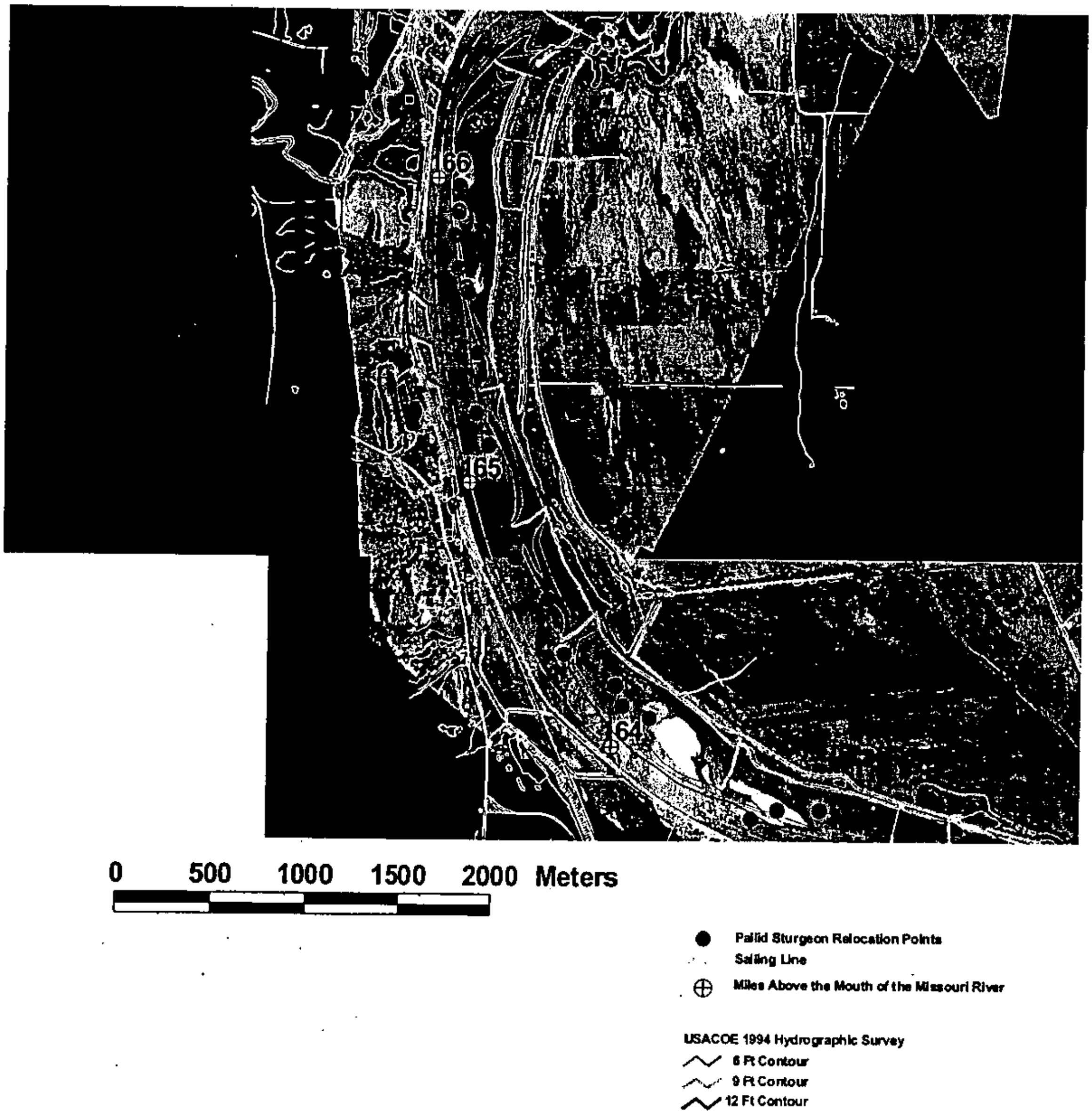

**Figure 9.** Pallid sturgeon relocations at Sandy Hook Bend of the Missouri River between river miles 164 and 166. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

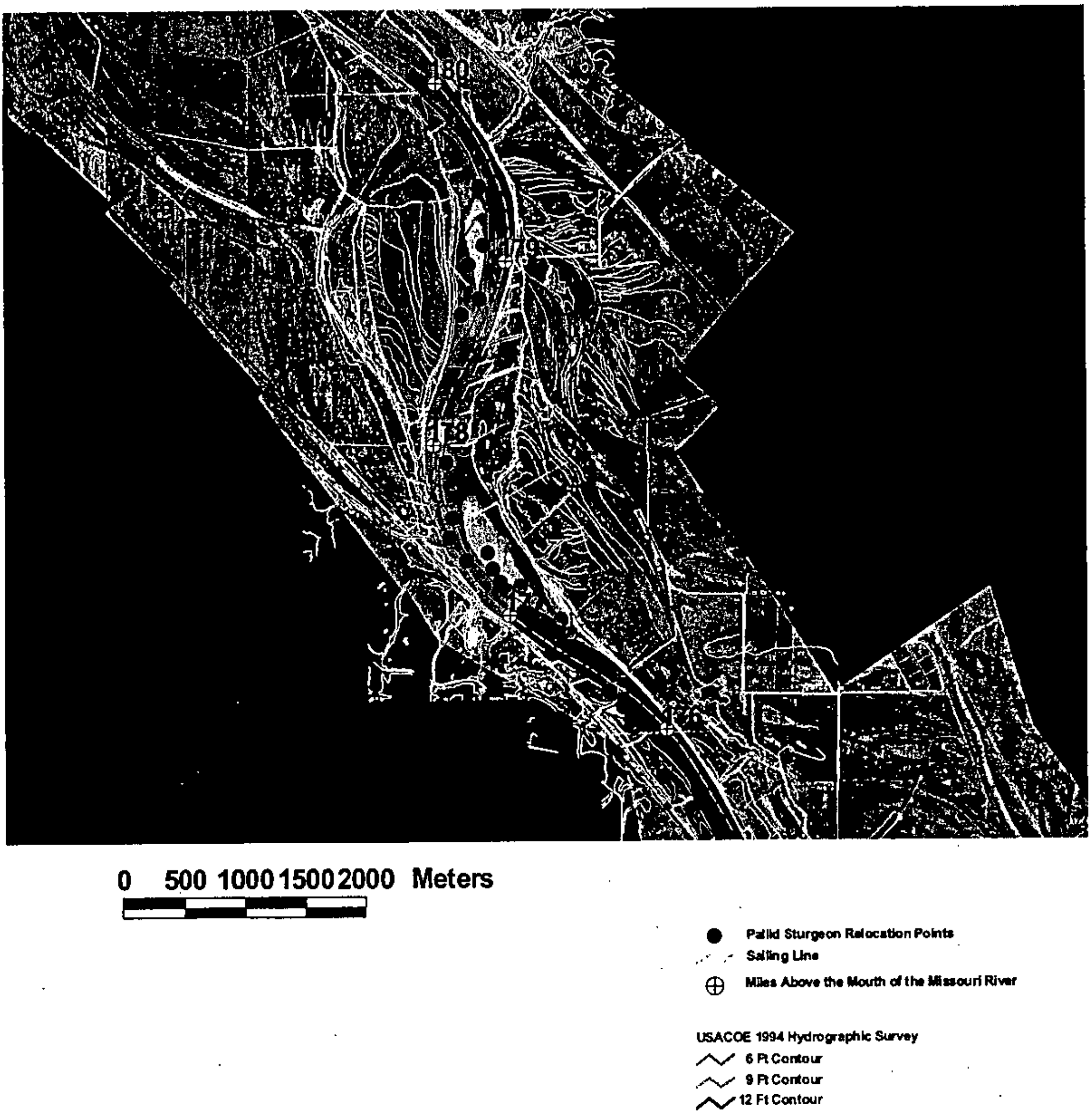

**Figure 10.** Pallid sturgeon relocations at Searcys Bend and McBaine Bend of the Missouri River between river miles 176 and 180. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

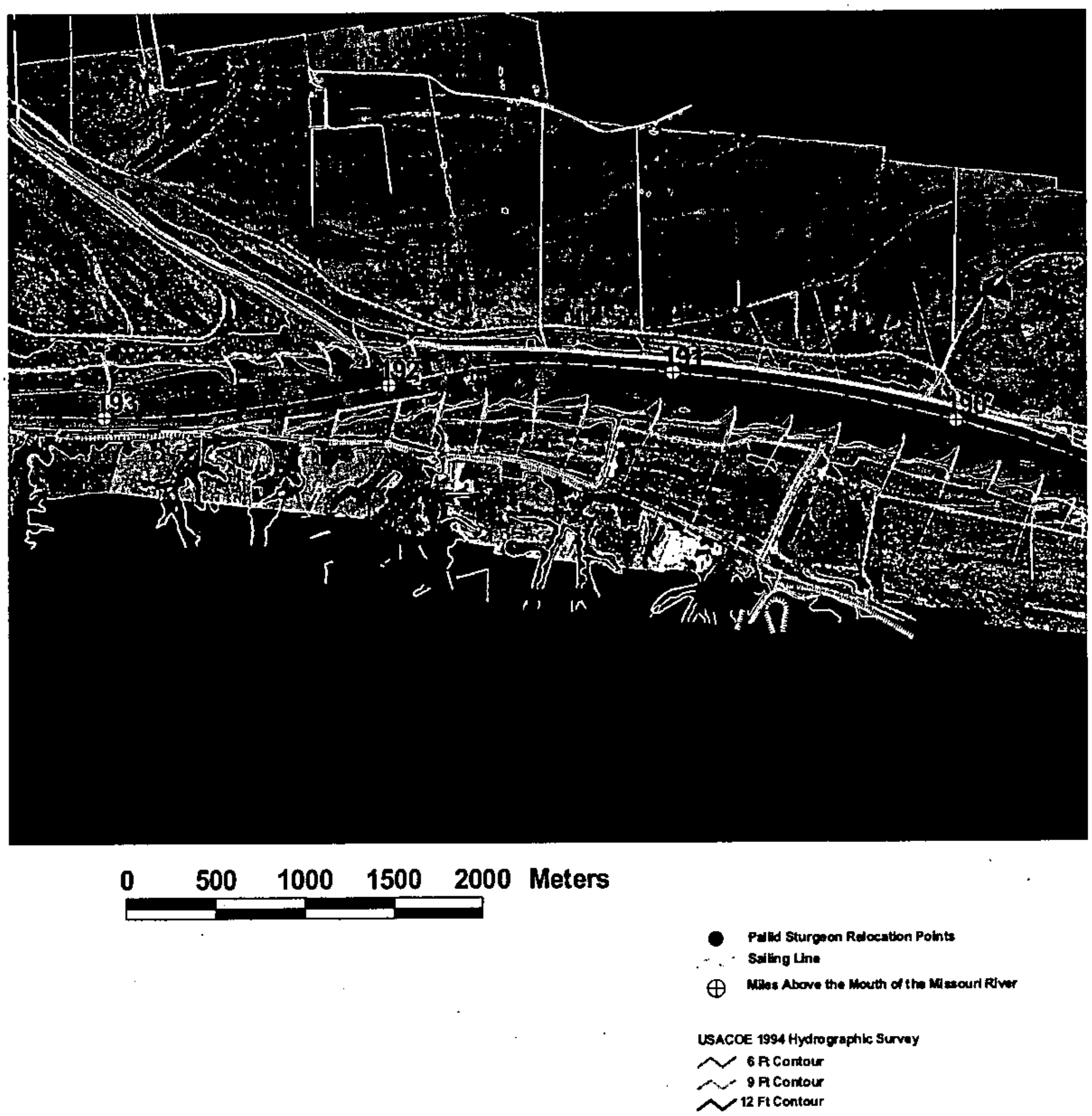

**Figure 11.** Typical river bend within the study area where sturgeon were not relocated. Diana Bends of the Missouri River between river miles 190 and 193. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

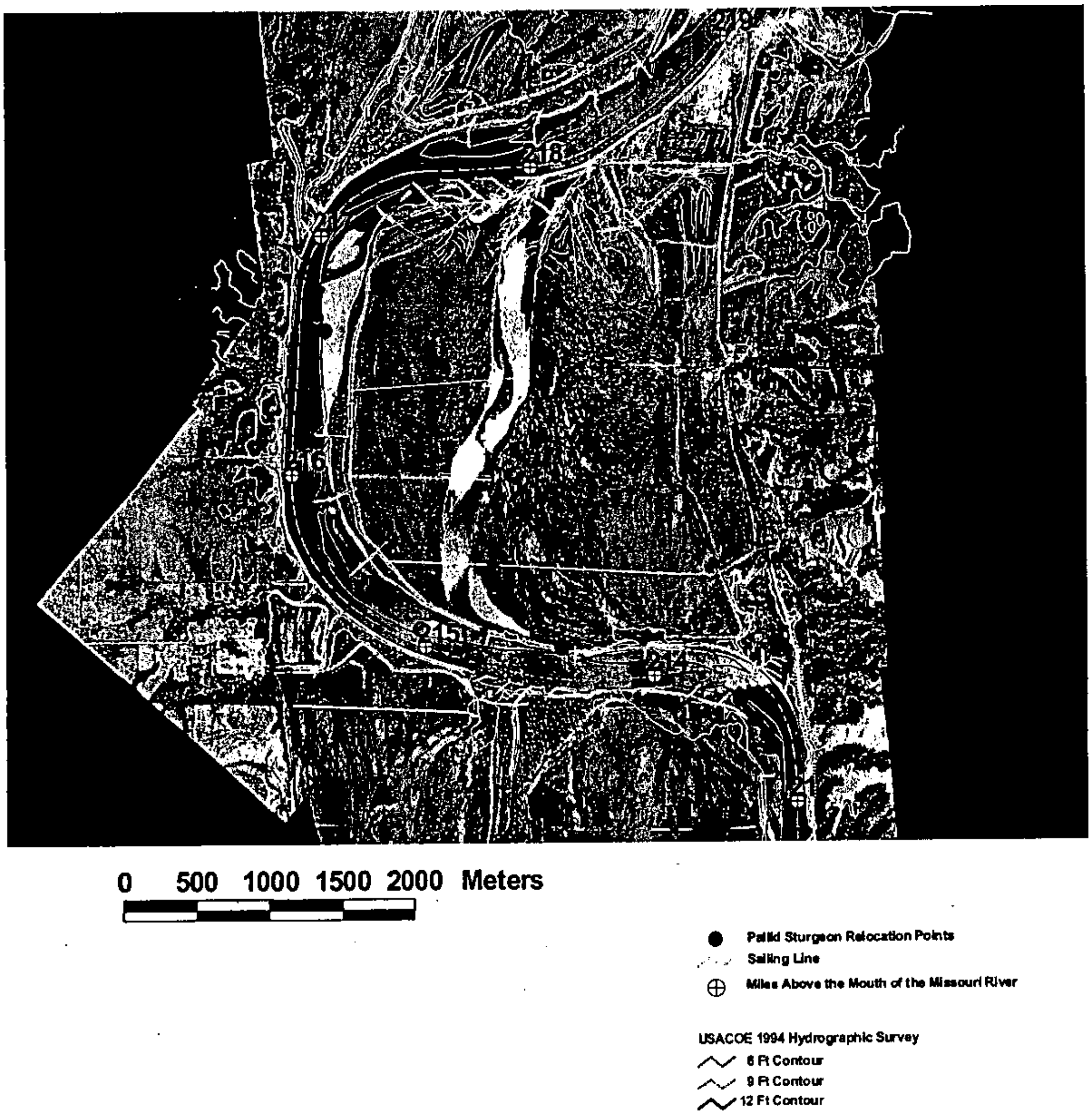

**Figure 12.** Sturgeon relocations within the Lisbon Bottoms and Jameson Island complex adjacent to the Big Muddy U.S. Fish and Wildlife Refuge between Missouri River miles 213 and 219. Point locations are plotted on 2000 DOQ photos collected during low flow. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

**Table 1.** Capture location, morphometric measurements, sex and taxonomic assignment of sturgeon implanted with ultrasonic transmitters and released into the lower Missouri River between 1995 and 1997.

| | Capture Data | | Morphometric Measurements | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish ID # | River | Approximate River Mile | Fork Length (mm) | Weight (kg) | Head Length (mm) | Interrostral (mm) | Mouth to Barbel (mm) | Inner Barbel (mm) | Outer Barbel (mm) | Sex | Species | Comment |
| 1378 | Mississippi | 846 | 866 | 1.73 | 268 | 123 | 41 | 55 | 146 | ND | pallid | |
| 1752 | Mississippi | 846 | 697 | 1.22 | 208 | 84 | 34 | 37 | 78 | ND | pallid | |
| 1754 | Mississippi | 846 | 824 | 1.89 | 255 | 115 | 43 | 37 | 92 | F | pallid | |
| 1379 | Mississippi | 110 | 880 | 2.54 | 255 | 112 | 45 | 35 | 93 | F | pallid | |
| 1751 | Mississippi | 110 | 776 | 1.84 | 220 | 88 | 40 | 38 | 75 | ND | pallid | |
| 1373 | Mississippi | 110 | 820 | 1.98 | 225 | 100 | 49 | 50 | 75 | ND | hybrid | |
| 1374 | ND | ND | 830 | 1.77 | 210 | 105 | 40 | 42 | 50 | ND | hybrid | 1 |
| 1376 | ND | ND | 732 | 3.30 | 195 | 78 | 38 | 37 | 55 | ND | hybrid | 1 |
| 1370 | ND | ND | 799 | 2.04 | 229 | 105 | 43 | 43 | 91 | ND | hybrid | 1 |
| 1753 | ND | ND | 737 | 1.40 | 196 | 79 | 39 | 38 | 47 | ND | hybrid | 1 |
| 1750 | ND | ND | 735 | 2.54 | 215 | 90 | 37 | 38 | 35 | ND | hybrid | 1,2 |
| 1755 | Mississippi | 110 | 786 | 1.59 | 219 | 109 | 43 | 27 | 60 | ND | pallid | |
| 1760 | Mississippi | 846 | 891 | 2.71 | 266 | 117 | 44 | 32 | 100 | ND | pallid | |
| 1759 | Mississippi | 846 | 886 | 3.10 | 261 | 113 | 45 | 41 | 92 | ND | pallid | |
| 1764 | Mississippi | 846 | 887 | 3.27 | 258 | 110 | 46 | 41 | 114 | ND | pallid | |

| Fish ID # | Capture Data |  | Morphometric Measurements |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | River | Approximate River Mile | Fork Length (mm) | Weight (kg) | Head Length (mm) | Interrostral (mm) | Mouth to Barbel (mm) | Inner Barbel (mm) | Outer Barbel (mm) | Sex | Species | Comment |
| 1767 | Mississippi | 846 | 839 | 2.80 | 230 | 105 | 40 | 41 | 104 | ND | pallid |  |
| 1763 | Mississippi | 846 | 949 | 3.95 | 260 | 116 | 44 | 45 | 102 | ND | pallid |  |
| 1758 | Mississippi | 846 | 805 | 2.31 | 237 | 110 | 46 | 41 | 116 | ND | pallid |  |
| 1757 | Mississippi | 846 | 836 | 2.54 | 241 | 116 | 43 | 44 | 108 | ND | pallid |  |
| 1765 | Mississippi | 846 | 803 | 2.31 | 220 | 91 | 45 | 44 | 98 | ND | pallid |  |
| 1766 | Mississippi | 846 | 843 | 2.58 | 240 | 110 | 41 | 32 | 72 | ND | pallid |  |
| 1768 | Mississippi | 846 | 772 | 2.38 | 241 | 105 | 41 | 39 | 102 | ND | pallid |  |
| 1762 | Mississippi | 846 | 875 | 2.98 | 254 | 125 | 44 | 27 | 83 | ND | pallid |  |
| 1756 | Mississippi | 110 | 712 | 1.21 | 200 | 82 | 45 | 41 | 69 | ND | hybrid |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1749 | Mississippi | 846 | 840 | 2.06 | 239 | 98 | 41 | 36 | 82 | ND | pallid |  |
| 2721 | Mississippi | 846 | 745 | 1.54 | 234 | 104 | 40 | 36 | 101 | ND | pallid |  |
| 2718 | Mississippi | 846 | 785 | 1.87 | 254 | 105 | 45 | 50 | 100 | F | pallid |  |
| 1761 | Mississippi | 846 | 802 | 2.58 | 248 | 101 | 42 | 39 | 105 | F | pallid |  |
| 2719 | Mississippi | 846 | 814 | 1.95 | 229 | 94 | 42 | 37 | 97 | ND | pallid |  |
| 2722 | Mississippi | 846 | 765 | 1.57 | 221 | 94 | 41 | 30 | 71 | ND | pallid |  |
| 2720 | Mississippi | 846 | 788 | 1.55 | 223 | 86 | 41 | 40 | 66 | ND | hybrid |  |

| | Capture Data | | Morphometric Measurements | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish ID # | River | Approximate River Mile | Fork Length (mm) | Weight (kg) | Head Length (mm) | Interrostral (mm) | Mouth to Barbel (mm) | Inner Barbel (mm) | Outer Barbel (mm) | Sex | Species | Comment |
| 2714 | Missouri | 159 | 793 | 2.06 | 215 | 85 | 42 | 37 | 86 | ND | pallid | |
| 2717 | Missouri | 159 | 765 | 1.53 | 230 | 111 | 28 | 25 | 60 | ND | pallid | |
| 2716 | ND | ND | 802 | 2.09 | 216 | 87 | 34 | 41 | 72 | ND | pallid | 1 |
| 2712 | Mississippi | 846 | 845 | 2.35 | 256 | 111 | 39 | 36 | 100 | ND | pallid | 1 |
| 2710 | Mississippi | 846 | 835 | 2.65 | 232 | 104 | 45 | 45 | 82 | ND | pallid | 1 |
| 2713 | Mississippi | 846 | 750 | 1.86 | 225 | 104 | 39 | 36 | 82 | ND | pallid | 1 |
| 2709 | Mississippi | 846 | 938 | 2.78 | 265 | 110 | 50 | 42 | 106 | F | pallid | 1 |
| 2711 | Mississippi | 846 | 805 | 1.91 | 231 | 94 | 40 | 42 | 75 | ND | hybrid | 1 |
| 2715 | Mississippi | 846 | 725 | 1.80 | 202 | 83 | 37 | 43 | 67 | F | hybrid | 1 |

Comments:
1 Fish initially collected and held by the Missouri Department of Conservation for propagation or research purposes
2 Both outer barbells damaged / shortened
ND = Not Determined

**Table 2.** Capture, location, release date, ultrasonic pinger assignment, and internal and external identification tag data for sturgeon implanted and released into the lower Missouri River from 1995 through 1997.

| Fish ID # | Species | Capture Data | | | Release Date | Ultrasonic Pinger Data | | Identification Tag Data | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Capture Date | River | Approximate River Mile | | Frequency (kHz) | Pulse Period (ms) | PIT Tag | T-bar | |
| 1378 | Pallid | 02/18/95 | Mississippi | 846 | 12/07/95 | 69.00 | 2492 | 002*058*274 | | |
| 1752 | Pallid | 02/24/95 | Mississippi | 846 | 12/07/95 | 65.54 | 2438 | 002*032*573 | | |
| 1754 | Pallid | 02/24/95 | Mississippi | 846 | 10/30/95 | 65.54 | 2531 | 001*572*864 | | |
| 1379 | Pallid | 04/07/95 | Mississippi | 110 | 10/23/95 | 69.00 | 2552 | 002*057*082 | | |
| 1751 | Pallid | 04/07/95 | Mississippi | 110 | 10/30/95 | 65.54 | 2391 | 002*039*569 | | |
| 1373 | Hybrid | 05/10/95 | Mississippi | 110 | 10/23/95 | 69.00 | 2196 | 002*056*010 | | |
| 1374 | Hybrid | ND | ND | ND | 10/23/95 | 69.00 | 2256 | 001*811*377 | | 1 |
| 1376 | Hybrid | ND | ND | ND | 12/07/95 | 69.00 | 2374 | 002*039*565 | | 1 |
| 1370 | Hybrid | ND | ND | ND | 10/23/95 | 69.00 | 2612 | 001*297*579 | | 1 |
| 1753 | Hybrid | ND | ND | ND | 10/30/95 | 65.54 | 2484 | 001*856*583 | | 1 |
| 1750 | Hybrid | ND | ND | ND | 10/30/95 | 65.54 | 2297 | 001*575*540 | | 1,2 |
| 1755 | Pallid | 03/30/96 | Mississippi | 110 | 04/01/96 | 65.54 | 2578 | 002*032*553 | | |
| 1760 | Pallid | 04/17/96 | Mississippi | 846 | 04/23/96 | 76.80 | 2250 | 002*528*602 | | |
| 1759 | Pallid | 04/17/96 | Mississippi | 846 | 04/23/96 | 76.80 | 2200 | 002*260*797 | | |
| 1764 | Pallid | 04/17/96 | Mississippi | 846 | 04/23/96 | 76.80 | 2450 | 002*303*275 | | |

| Fish ID # | Species | Capture Data | | | | Ultrasonic Pinger Data | | Identification Tag Data | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Capture Date | River | Approximate River Mile | Release Date | Frequency (kHz) | Pulse Period (ms) | PIT Tag | T-bar | |
| 1767 | Pallid | 04/18/96 | Mississippi | 846 | 04/23/96 | 76.80 | 2600 | 001*808*365 | | |
| 1763 | Pallid | 04/19/96 | Mississippi | 846 | 04/23/96 | 76.80 | 2400 | 001*818*070 | | |
| 1758 | Pallid | 04/20/96 | Mississippi | 846 | 04/24/96 | 65.54 | 2719 | 002*303*359 | | |
| 1757 | Pallid | 04/20/96 | Mississippi | 846 | 04/24/96 | 65.54 | 2672 | 002*063*358 | | |
| 1765 | Pallid | 04/20/96 | Mississippi | 846 | 04/24/96 | 76.80 | 2500 | 001*301*859 | | |
| 1766 | Pallid | 04/20/96 | Mississippi | 846 | 04/24/96 | 76.80 | 2550 | 002*035*773 | | |
| 1768 | Pallid | 04/20/96 | Mississippi | 846 | 04/24/96 | 76.80 | 2650 | 002*353*586 | | |
| 1762 | Pallid | 04/20/96 | Mississippi | 846 | 04/23/96 | 76.80 | 2350 | 002*038*773 | | |
| 1756 | Hybrid | 04/14/96 | Mississippi | 110 | 04/16/96 | 65.54 | 2625 | 001*572*520 | | |
| 1749 | Pallid | 04/19/96 | Mississippi | 846 | 10/29/96 | 65.54 | 2203 | 001*818*626 | | |
| 2721 | Pallid | 04/20/96 | Mississippi | 846 | 10/29/96 | 69.00 | 2203 | 002*535*554 | | |
| 2718 | Pallid | 04/20/96 | Mississippi | 846 | 10/29/96 | 69.00 | 2029 | 002*529*086 | | |
| 1761 | Pallid | 04/20/96 | Mississippi | 846 | 10/29/96 | 76.80 | 2300 | 001*815*361 | | |
| 2719 | Pallid | 04/20/96 | Mississippi | 846 | 10/29/96 | 69.00 | 2087 | 001*572*080 | | |
| 2722 | Pallid | 04/20/96 | Mississippi | 846 | 10/29/96 | 69.00 | 2261 | 001*600*316 | | |
| 2720 | Hybrid | 04/20/96 | Mississippi | 846 | 10/29/96 | 69.00 | 2145 | 002*532*834 | | |
| 2714 | Pallid | 04/26/97 | Missouri | 159 | 06/20/97 | 60.00 | 2350 | 115729232A | | |

| Fish ID # | Species | Capture Data | | | Ultrasonic Pinger Data | | | Identification Tag Data | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Capture Date | River | Approximate River Mile | Release Date | Frequency (kHz) | Pulse Period (ms) | PIT Tag | T-bar | |
| 2717 | Pallid | 06/28/97 | Missouri | 159 | 06/29/97 | 60.00 | 2500 | 115649190A | | |
| 2716 | Pallid | ND | ND | ND | 06/20/97 | 60.00 | 2450 | 115555144A | | 1 |
| 2712 | Pallid | 4/26-30/97 | Mississippi | 846 | 06/20/97 | 60.00 | 2200 | 115552326A | PS7764 | 1 |
| 2710 | Pallid | 4/26-30/97 | Mississippi | 846 | 06/20/97 | 60.00 | 2100 | 115557766A | PS7759 | 1 |
| 2713 | pallid | 4/26-30/97 | Mississippi | 846 | 06/20/97 | 60.00 | 2300 | 115675446A | PS7758 | 1 |
| 2709 | pallid | 4/26-30/97 | Mississippi | 846 | 06/20/97 | 60.00 | 2050 | 115532594A | PS7756 | 1 |
| 2711 | hybrid | 4/26-30/97 | Mississippi | 846 | 06/20/97 | 60.00 | 2150 | 115551592A | PS7754 | 1 |
| 2715 | hybrid | 4/26-30/97 | Mississippi | 846 | 06/20/97 | 60.00 | 2400 | 115634666A | PS7761 | 1 |

Comments:
1 Fish initially collected and held by the Missouri Department of Conservation for propagation or research purposes
2 Both outer barbells damaged / shortened
ND = Not Determined

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## APPENDIX A

**Practical Constraints Analysis for Telemetry in the Missouri and Mississippi Rivers. Grant Systems Engineering.**

# Practical Constraints Analysis for Telemetry

***in the Missouri and Mississippi Rivers***

DOCUMENT NO. 128-100

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## EXECUTIVE SUMMARY

Contained herein are the results of experiments performed on the Missouri river system at RF and ultrasonic frequencies. These experiments were performed to characterize the environment, or practical constraints, and compare them with models or algorithms used to predict system performance in an effort to determine the most effective telemetry system for pallid sturgeon research. Experiments showed reasonable agreement with the models thus helping validate their general use. Experiments and model predictions also ruled out the use of RF telemetry and supported careful use of ultrasonic telemetry.

# Guest

**Remote Downlevel Document**
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# 1. INTRODUCTION

In order to choose the most suitable technology for pallid sturgeon research on the Missouri and lower Mississippi rivers, the entire telemetry system must be considered from transmitter through receiver, through data analysis platform. Most modern telemetry receivers provide standard serial interfaces to allow direct transfer of digital data. Therefore, the critical considerations become the front end performance of the data collection system and the functional options provided. Functional options are strictly in the domain of equipment manufacturers who judge, by whatever means, which options are useful to encode in the equipment firmware. Performance, however, is influenced both by equipment quality and the physics governing the medium chosen.

Obviously the physics governing a particular medium play a critical role in determining whether technology employing that medium will be useful. No matter how much you offer to pay nature to change its laws, it will not relent. Therefore, it is necessary to fully characterize the media to be considered so that, in conjunction with the technology that is available, system performance can be estimated and compared.

To characterize a medium with a test system, all components of the test system must be understood and all parameters not dealing with the medium must be fixed at a known value or isolated. In telemetry, all systems can be reduced to the same fundamental functional components and the same fundamental equations incorporating transmitter output, path loss, receiver system gain and receiver sensitivity.

## 1.1. Objectives

The objectives of this study are as follows:

1. To measure the loss in the Missouri and lower Mississippi rivers under worst case, average case and best case conditions for the following:
    - RF at 50 MHz
    - RF at 150 MHz
    - Ultrasonic at 32 kHz
    - Ultrasonic at 69 kHz
2. To characterize the background noise in both the RF and Ultrasonic environments.

3. To validate system models with results so models can be used to evaluate vendor equipment.
4. To rule out or confirm the likely success of RF or ultrasonic systems in general for pallid sturgeon research efforts in the Missouri and lower Mississippi rivers.

# 2. BACKGROUND

Successful prediction of system performances comes from the development of models that include most factors that influence signal transmission and reception. Although a model cannot exactly characterize any particular environment because of the overwhelming number of unmeasurable and unpredictable variables, it can be used to design a system, without costly experimentation, that will have a high probability success. Further assurance of performance can be achieved by building a system with performance well above the minimum that is predicted necessary through the models.

## 2.1. Note on Decibels (dB)

Throughout, reference will be made to decibels. Decibels are simply ratios expressed logarithmically. For example, a power ratio of 10:1 is expressed as,

$$10\log\left(\frac{10}{1}\right) = 10 \text{ dBm}$$

and a voltage ratio of 10:1 is expressed as,

$$20\log\left(\frac{10}{1}\right) = 20 \text{ dB}$$

A voltage ratio is double the equivalent power ratio in decibels to preserve Ohms law such that a 10 dB change in power will also produce a 10 dB change in voltage.

Decibels are used because, in radio and ultrasonic systems, ratios can become quite large or quite small, thereby making them unwieldy. For example, a range between 100,000,000,000,000 and .000,000,000,000,001 is simply a range between +140 dB and -150 dB. Also, decibels are simply added rather than multiplied.

Often decibels are expressed as dBm or dBμPa. These ratios are with respect to specific units such as one milliwatt or one micropascal.

## 2.2. RF Model

RF systems depend on the propagation of an electromagnetic wave from a transmitter to a receiver. Electromagnetic waves are formed by current traveling along a wire setting up a series of oscillating electric and magnetic fields that travel well through non-conducting media.

### 2.2.1. *System Equation*

In order to successfully receive a signal, the RF system equation must be satisfied. This equation is,

$$P_t - L_p + G_r - L_r - N_r \geq SNR_{\min}$$

where,

$P_t$ is the transmitter power

$L_p$ is the path loss

$G_r$ is the receive antenna gain

$L_r$ is the transmission line loss at the receiver

$N_r$ is the noise level in the receiver

$SNR_{\min}$ is the minimum signal to noise ratio required for detection

### 2.2.2. *Transmitter Power*

The transmitter power is the effective radiated power relative to a dipole (ERP) or an isotropic (equally in all directions) radiator (EIRP). The ERP is equivalent to the EIRP-2.15 dB and is expressed in dBm as specified by the transmitter manufacturer. Fisheries transmitters commonly exhibit ERPs between -35 and +6 dBm.

### 2.2.3. *Path Loss*

Evaluating the path loss between an underwater transmitter and a surface receiver is complex involving contributions from attenuation by water, refraction and reflection through the air-water interface, and spreading loss. Mathematically,

$$L_p = L_w + L_r + L_s$$

where,

$L_p$ is the path loss

$L_w$ is the attenuation in water

$L_r$ is the loss from refraction and reflection

$L_s$ is the spreading loss

Attenuation in water is governed by the frequency used, the conductivity of the water and the water temperature. This relationship is described in Appendix A.

As radio waves propagate to the surface, they encounter an abrupt change in properties at the air water interface. As with light, this tends to reflect a large amount of the energy back down into the water. Some energy does escape, however, although it undergoes severe attenuation especially in perpendicular (nearly horizontal) polarization and at large refraction angles. This is what causes vertical antennas to perform better for fisheries telemetry.

Spreading loss occurs with any radiating object. As the signal propagates away from the source, it spreads out over a larger area. As a result it becomes diluted causing it to weaken. It is described by the equation,

$$L_s = 22 + 20\log\left(\frac{r}{\lambda}\right)$$

where,

$r$ is the distance from the transmitter in m

assuming isotropic references are used.

### 2.2.4. Receive Antenna Gain

Antennas can be constructed in various configurations and sizes. Generally, larger antennas provide greater gain. Higher gain means that the receiver will be capable of detecting weaker signals thus extending the range of the system. Gain is usually specified in antenna literature.

### 2.2.5. Transmission Line Loss

Cables attached between antennas and receivers exhibit finite amounts of loss. As the cables become appreciably long relative to their loss specifications, they will offset antenna gain thereby reducing the performance of the system. For long transmission lines, this effect can be eliminated by using line amplifiers. Loss specifications for cable are provided by the manufacturer.

### 2.2.6. Noise

Noise in a receiver can come from two basic sources. It can be natural noise generated by the motion of electrons or it can be man made noise generated by machinery, transmitters, etc. Noise is generally broad banded meaning that the wider the receiver bandwidth, the greater the overall noise level. Obviously, any signal appreciably below the noise level will be undetectable, therefore it is preferable to keep the noise level as low as possible so that the detectable signal level is also as low as possible. Many modern receivers have noise levels close to -145 dBm.

### 2.2.7. Signal to Noise Ratio

The ratio of the desired signal to the noise floor determines the ease with which the desired signal can be detected. Naturally the higher the ratio, the easier the signal is to receive. The ear is a complicated instrument capable of detecting certain signals close to, and even below the noise floor. Common receiver detector circuitry, however, is not quite so sophisticated and usually requires a signal to noise ration of about 10 dB to perform adequately.

## 2.3. Ultrasonic Model

Ultrasonic systems depend on the propagation of pressure waves from a transmitter to a receiver. Pressure waves are formed by a transducer which uses electric signals to move a diaphragm creating variations in pressure that travel well through dense media.

### *2.3.1. System Equation*

To succeed, an ultrasonic system must satisfy the sonar equation:

$$SL - TL - NL + DI \geq DT$$

where,

$SL$ is the source level of the transmitter

$TL$ is the transmission loss

$NL$ is the background noise level

$DI$ is the directivity index of the hydrophone

$DT$ is the detection threshold

This equation incorporates the same fundamental parameters as the RF equation, however, they are expressed in conventional terms for ultrasonics.

### *2.3.2. Source Level*

The source level is the amount of sound pressure produced at a distance of 1m from the transmitter . It is specified by the manufacturer. Levels of approximately 140 dBμPa @ 1m are common.

### *2.3.3. Transmission Loss*

In short range ultrasonics, the primary and most predictable source of transmission loss is simply the spreading loss. This is expressed as,

$$TL = 20 \log r$$

where,

$r$ is the distance from the source in m

Obstructions, plants and interference patterns can add significantly to this loss.

### *2.3.4. Directivity Index*

The directivity index is an expression of how "directive" the hydrophone is. It is expressed in dB and it has the effect of increasing the wanted signal strength relative to the noise as gain does in an RF antenna. This is specified by the hydrophone manufacturer.

### *2.3.5. Noise Level*

Noise has a much more significant influence on ultrasonic systems than radio systems. Ultrasonic noise in rivers is primarily created by turbulence around rocks or even the hydrophone and boat. As with RF systems, it is necessary to keep the noise to a minimum to increase system performance. Therefore, a great deal of caution must be taken in mounting the hydrophone in a streamlined package and keeping boat movement to a minimum. Background noise can be typically in the range of 40 to 90 dBμPa/Hz.

### *2.3.6. Detection Threshold*

The detection threshold is basically the same as the minimum signal to noise ratio in RF systems. In ultrasonics, it includes the receiver bandwidth, detector integration time and the desired combination of probabilities for detection and false detection. The lower the detection threshold, the more sensitive the receiver is. It can be on the order of 30 dB.

# 3. PREPARATION

## 3.1. RF

The RF experimental procedure involves using a calibrated signal generator to supply a known signal to an underwater transmit antenna. The underwater antenna consists simply of a coaxial cable with the shield stripped off the end for a length equivalent to one wavelength underwater. The underwater wavelength is determined from the dielectric constant evaluated using the equations for underwater loss. It is found to be approximately 0.66 m for 50 MHz and 0.22 m for 150 MHz.

The receive antenna is exactly the same as the transmit antenna and it is attached to a calibrated spectrum analyzer to measure received signal strength precisely. Both antennas must be held very still during measurement and at a known distance from each other. The antennas must be away from all metal objects including boats. By supporting the antennas on wooden dowels extended as far as possible below the surface of the water, this was achieved.

## 3.2. Ultrasonic

The equipment that was used for the ultrasonic measurements was the same as that used for the RF measurements, that is to say, a signal generator and spectrum analyzer. Unfortunately these devices are designed for $50\ \Omega$ loads and express power in dBm with reference to $50\ \Omega$ loads only. It is necessary to derive formulae to convert dBm to source levels and received sound pressures accordingly.

### *3.2.1. Projector Equations*

A signal generator with a $50\ \Omega$ output impedance drove a projector with an impedance of $2\text{k}\ \Omega$ in parallel with 9.5 nF. This is represented by the following schematic diagram:

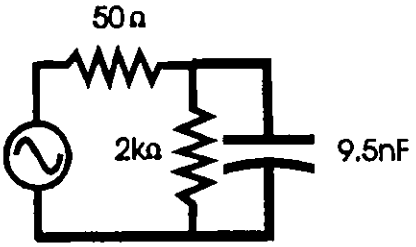


*Figure 1: Equivalent Circuit for Signal Generator and Projector*

We need to determine the voltage across the projector for a given signal generator output specified in dBm since the source level is specified with respect to a hydrophone voltage.

Voltage is related to power as follows,

$$V = \sqrt{P \times R}$$

R is 50 Ω and P is determined by,

$$P = 10^{\frac{P_{dBm}}{10}}$$

The voltage, thus calculated, is the rms voltage across a matched 50 ohm load. The source rms voltage is actually double this value. Therefore,

$$V_s = 2 \times V$$

Since there is a capacitor in parallel with the projector resistance, the impedance must be converted to its complex equivalent. This is evaluated as follows,

$$Z_h = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

where,

$$Z_1 = 2000$$

$$Z_2 = \frac{1}{j\omega C}$$

Thus the projector voltage is given by,

$$\frac{V_p}{V_s} = \frac{Z_h}{Z_h + Z_s}$$

This voltage can be compared to the 10 V peak to peak or 7.07 Vrms voltage used by Vemco to measure their specified source levels. The ratio in decibels can be applied to the Vemco specified source levels to determine the actual output (see Appendix B). If we use a signal generator output of 0 dBm, we can derive a formula for direct conversion of the signal generator amplitude reading to source level.

With the signal generator set to 0 dBm, the following source levels are achieved:

| Frequency (kHz) | Source Level (dBµPa @ 1m) |
|---|---|
| 32 | 113 |
| 50 | 120 |
| 65 | 116 |
| 69 | 113 |

*Table 1: Source Level for 0 dB Signal Generator Setting*

These values can be applied to the following equation to determine the generated source level:

$$SL = SL_{0dbm} + P_{\text{signal generator}}$$

### 3.2.2. Hydrophone Equations

For the hydrophone, Vemco literature states the open circuit output voltage for a 1 µPa sound pressure (hydrophone sensitivity). We are using a spectrum analyzer with a 50 ohm input impedance as our detector. As a result, we need to know how this sound pressure relates to the observed signal level in dBm.

The hydrophone has an output impedance of 75 ohms, therefore, following is the equivalent circuit.

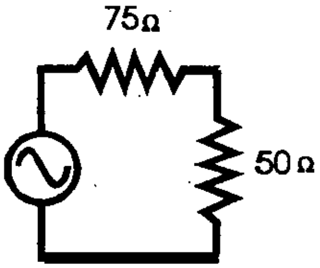


*Figure 2: Equivalent Circuit for Hydrophone and Spectrum Analyzer*

The voltage across the 50 ohm load is calculated as follows:

$$\frac{V_r}{V_h} = \frac{Z_r}{Z_h + Z_r}$$

Since,

$$P = \frac{V^2}{R}$$

the power in dBm can be calculated using,

$$P_{dBm} = 10\log\left(\frac{P}{1\text{mW}}\right)$$

Table 2 shows the resulting power readings for 1 µPa at various frequencies.

| **Frequency (kHz)** | **Power Reading (dBm/µPa)** |
|---|---|
| 32 | -149 |
| 50 | -147 |
| 65 | -154 |
| 69 | -152 |

*Table 2: Power Reading on Spectrum Analyzer for 1 µPa Sound Pressure on Hydrophone*

These values can be used in the following formula to convert power readings to sound pressure:

$$P_{dB\mu Pa} = P_{dBm} - P_{dBm/\mu Pa}$$

## 4. EQUIPMENT

The following is the equipment list used in preparation for the experiments:

| QTY | Description | Part No. | Source |
|---|---|---|---|
| 1 | 150 MHz Receiver | SRX 400 | Lotek |
| 1 | 50 MHz Receiver | SRX 400 | Lotek |
| 1 | 75 MHz Ultrasonic Receiver | VR-60 | Vemco |
| 1 | 35-75 kHz Signal Generator | | GSE |
| 1 | 50-150 MHz Signal Generator | | GSE |
| 1 | Spectrum Analyzer | | GSE |
| 1 | Projector | | Vemco |
| 1 | Hydrophone | | Vemco |
| 250 ft | 50 Ohm Coax Cable (RG58) | 9311 | Belden/Newark |
| 10 | BNC Connectors | 227079-5 | AMP/Newark |
| 1 | Crimp Tool (if crimp connectors used) | 220190-1/220189-1 | AMP/Newark |
| 1 | Cable Stripper (if crimp connectors used) | 603995-6 | AMP/Newark |
| 250 ft | 1/4 Inch Rope (nylon) | | Local Supply |
| 4 | Floats | | Local Supply |
| 4 | 5 lb. Weights | | Local Supply |
| 2 | Boat | | NBS |
| 2 | Overboard Antenna Rigging | | |
| 1 | Distance Measurement Equipment | | |
| 1 | Butane Soldering Iron | WSTA-3 | Weller/Newark |
| 1 roll | 60/40 Solder | | Newark |
| 5 | Electrical Tape | | Local Supply |
| 100 | Cable Ties (black outdoor type) | | Newark |
| 100 | Waterproof Cable Markers | | Newark |
| 1 | Pliers | | Local Supply |
| 1 | Side Cutters | | Local Supply |
| 1 | Multimeter | | Radio Shack |
| 1 | 50 MHz Test Transmitter | | Lotek |
| 1 | 150 MHz Test Transmitter | | Lotek |
| 1 | 75 kHz Ultrasonic Test Transmitter | | Vemco |
| 1 pair | Two Way Radios | | |

# 5. RESULTS

## 5.1. RF

The following are the results obtained through experimentation at RF frequencies.

### *5.1.1. Conductivity Measurements*

The model for RF propagation loss in water is based on conductivity (or salinity), temperature and frequency. By taking measurements of conductivity and temperature throughout the study area, we can obtain information on the variability of conditions affecting propagation and determine where the best, average and worst case conditions are.

Ideally, we would prefer to have data collected over a long term showing the conditions as they occur seasonally and over several years. This type of information is collected by water quality stations located along the Missouri and Mississippi rivers. Appendix C contains information from stations within the study area which is summarized in Table 3 and Table 4.

| **Location** | **Low (μS/cm)** | **Average (μS/cm)** | **High (μS/cm)** |
|---|---|---|---|
| Osage River, St. Thomas | 206 | 276 | 315 |
| Gasconade River, Jerome (1992 only) | 293 | 316 | 345 |
| Missouri River, Herman | 266 | 457 | 668 |
| Mississippi River, Grafton | 325 | 452 | 602 |

*Table 3: Measured Conductivity Ranges by Water Quality Stations, 1992&1993*

| **Location** | **Low (°C)** | **Average (°C)** | **High (°C)** |
|---|---|---|---|
| Osage River, St. Thomas | 3.0 | 14.0 | 24.0 |
| Gasconade River, Jerome (1992 only) | 6.5 | 15.0 | 25.0 |
| Missouri River, Herman | 3.0 | 14.3 | 26.5 |
| Mississippi River, Grafton | 0.5 | 13.1 | 26.5 |

*Table 4: Measured Temperature Ranges by Water Quality Stations, 1992&1993*

Unfortunately, these water quality stations are few and far between. We had to determine the variability expected within a smaller segment of the river system. On September 20th, 1994, measurements were made between Boonville and Hermann, along the Missouri River and in some of its tributaries. Although the temporal sample size was extremely limited, the spatial sample size was adequate to indicate the variability expected between stations. Variations over time could be inferred from the water quality stations. The results are shown in Table 5.

| **Location** | **Conductivity (µS/cm)** | **Temperature (°C)** |
|---|---|---|
| Boonville | 758 | 24.1 |
| Rochport | 756 | 24.0 |
| Perche Creek (Sept. 22) | 1,183 | 21.2 |
| Wooldridge (stream) | 675 | 19.1 |
| Marion | 754 | 24.3 |
| Osage River | 256 | 26.1 |
| Chamois | 722 | 24.6 |
| Gasconade River | 319 | 25.1 |
| Hermann | 704 | 24.6 |

*Table 5: Water Conductivity and Temperature between Franklin and Hermann, Sept. 20&22, 1994*

From these data, we obtain the following summary:

| **Parameter** | **Low** | **Average** | **High** |
|---|---|---|---|
| Conductivity | 256 µS/cm | 681 µS/cm | 1,183 µS/cm |
| Temperature | 19.1 °C | 23.7 °C | 26.1 °C |

*Table 6: Range of Water Conductivity and Temperature between Franklin and Hermann, Sept. 20&22, 1994*

The lowest conductivity observed from the water quality stations was 206 µS/cm and the highest was 668 µS/cm. Since conductivity adversely affects propagation, these could be taken as the best case and worst case conductivity conditions, however, we observed levels as high as 1,183 µS/cm in Perche Creek. Therefore, we will assume the best case to be 206 µS/cm and the worst case to be 1,183 µS/cm.

The effect of temperature variations depend on the conductivity and frequency, however, this effect is usually only slight. To determine the worst and best cases in the model, the extremes in temperature must be included at each conductivity level. In the data, temperatures ranged from 0.5 °C to 26.5 °C with an average of 14.1 °C.

### 5.1.2. RF Model Calculations

Appendix D contains the calculation worksheets used to determine the best, average and worst case reception depths expected for radio telemetry assuming a minimum range of

500m. Typical transmitter powers were used. Note that 150 MHz transmitters can be constructed with much higher power output than 50 MHz transmitters. The results are summarized in Table 7.

| Frequency | Best Case (m) | Average Case (m) | Worst Case (m) |
|---|---|---|---|
| 50 MHz | 4.03 | 2.13 | 0.73 |
| 150 MHz | 8.91 | 5.05 | 1.83 |

*Table 7: Best, Average and Worst Case Reception Depths at 500m Range*

So far, the estimates for RF performance have been based entirely on an algorithm with little empirical data to support it. In order to satisfy the need to support theory with practice, experiments were held to verify the model. By making signal strength measurements at various distances in water, it was possible to measure the loss per meter. This was done at both 50 MHz and 150 MHz in different water quality environments to provide several comparative scenarios.

### 5.1.3. 50 MHz RF Measurements

Initial experiments were held in Perche Creek where the measurements of Table 8 were obtained.

| Distance (feet) | Transmitted Signal Strength (dBm) | Received Signal Strength (dBm) |
|---|---|---|
| 4 | 10 | -43 |
| 6 | 10 | -54 |
| 8 | 10 | -60 |
| 10 | 10 | -60 |
| 15 | 10 | -56 |
| 15 | 10 | -70 |
| 25 | 10 | -63 |
| 25 | 10 | -74 |
| 50 | 10 | -77 |
| 50 | 10 | -80 |
| 75 | 10 | -84 |

*Table 8: 50 MHz RF Measurements in Perche Creek, Cond.=1,183μS/cm, Temp=21.2℃*

These results were graphed and compared to the expected results obtained from the model (Figure 3). The results were unexpected as there was a dramatic divergence between the received signal strength predicted and the actual signal strength received. The actual signal remained surprisingly strong throughout a range of several tens of feet.

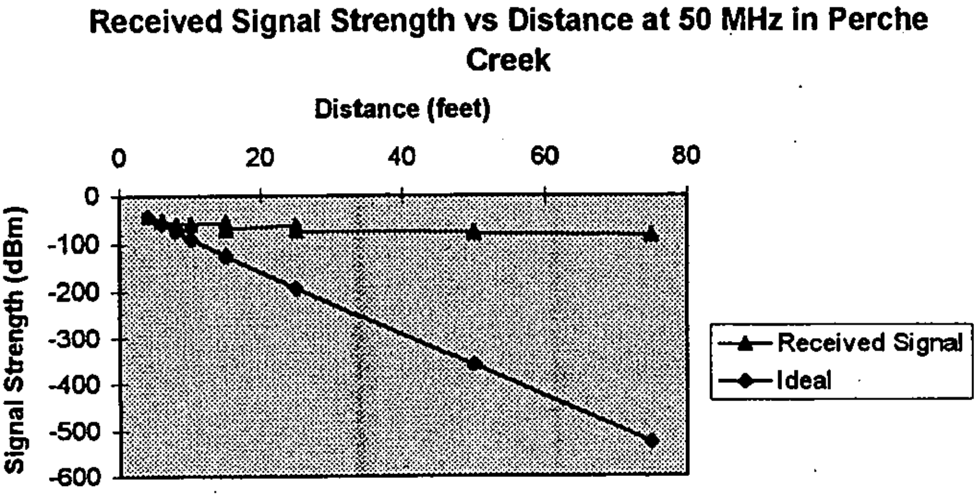


*Figure 3*

More data was obtained by making similar measurements in the Missouri River. Unlike Perche Creek, the currents were very strong and it became more difficult to maintain stable platforms and known distances between antennas. The results are in Table 9.

| Distance (feet) | Transmitted Signal Strength (dBm) | Received Signal Strength (dBm) |
|---|---|---|
| 6 | 10 | -41 |
| 10 | 10 | -40 |
| 15 | 10 | -45 |
| 20 | 10 | -43 |
| 25 | 10 | -50 |
| 50 | 10 | -54 |
| 75 | 10 | -58 |

*Table 9: 50 MHz RF Measurements in Missouri River, Cond.=766μS/cm, Temp=22.7℃*

These results, when plotted, exhibited much the same characteristics as those from Perche Creek (Figure 4). Again the signal strengths were far greater than expected from the model.

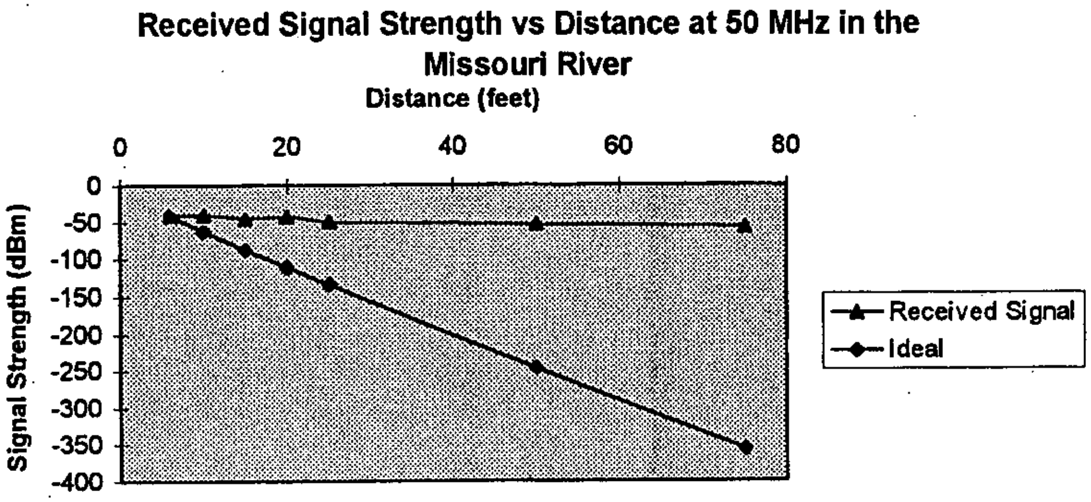


*Figure 4*

An explanation for the differences seemed to lie in the fact that the signal strength fluctuated dramatically especially as the boats turned and the coax from the antennas was moved. It appeared as though an appreciable amount of signal was traveling through the air rather than through the water. Since attenuation in the air is much less than in the water, a much lower attenuation of signal with distance would result.

In order to prove this hypothesis, the apparatus was moved to a much more stable and controllable environment at the Midwest Science Center facility. Here, an experimental pond was used. The dowels supporting the antennas were driven into the bed of the pond at a given distance from each other. The cables leading to the antennas were submerged to the bank where the signal generator and spectrum analyzer were placed as close as possible to the water's edge and as far apart from each other as possible to maximize isolation. This extensive isolation would ensure that the majority of the signal received travels through the water from the transmit antenna to the receive antenna only.

Table 10 shows the resulting measurements which are plotted in Figure 5.

| **Distance (feet)** | **Transmitted Signal Strength (dBm)** | **Received Signal Strength (dBm)** |
|---|---|---|
| 6.2 | 10 | -40 |
| 10.2 | 10 | -53 |
| 16.5 | 10 | -74 |
| 22.6 | 10 | -91 |

*Table 10: 50 MHz RF Measurements in Pond, Cond.=591μS/cm, Temp=16.2°C*

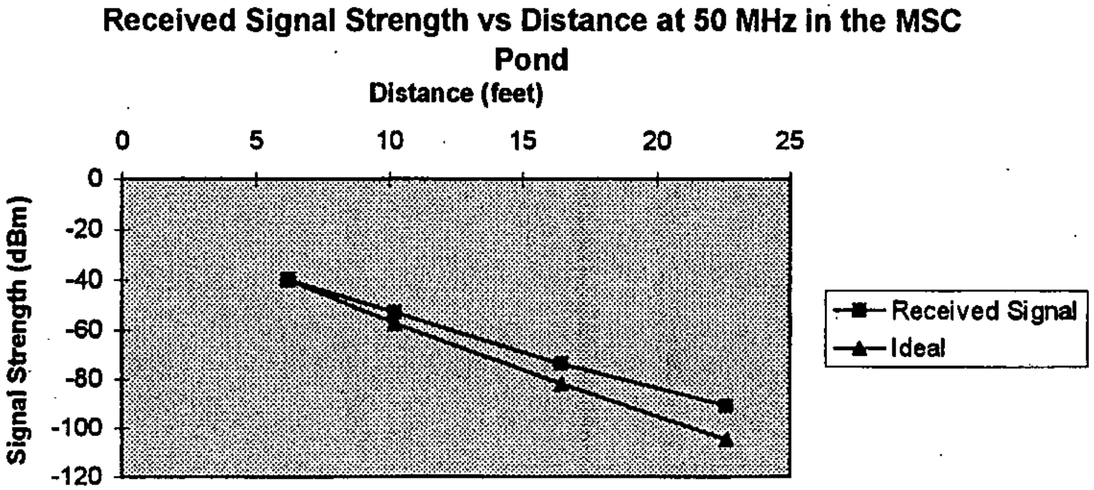


*Figure 5*

The results from the MSC pond were much closer to the model with the model being slightly more conservative in signal strength predictions. Linear regression analysis showed that the data represented a loss of 10.3 dB/m whereas the model predicted a loss of 10.73 dB/m. This is acceptable if the model similarly predicts performance in other conditions.

### *5.1.4. 150 MHz RF Measurements*

At 150 MHz, a similar series of experiments took place beginning in Perche Creek. The measurements obtained are shown in Table 11 and plotted in Figure 6.

| Distance (feet) | Transmitted Signal Strength (dBm) | Received Signal Strength (dBm) |
|---|---|---|
| 6 | 10 | -77 |
| 8 | 10 | -76 |
| 10 | 10 | -88 |
| 13 | 10 | -84 |

*Table 11: 150 MHz RF Measurements in Perche Creek, Cond.=1,183μS/cm, Temp=21.2℃*

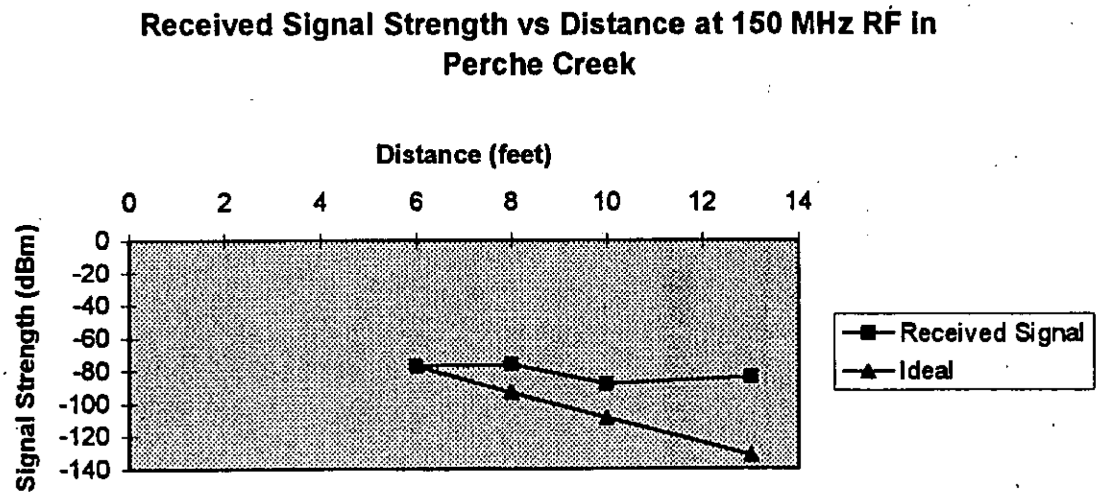

Received Signal Strength vs Distance at 150 MHz RF in Perche Creek

*Figure 6*

As with 50 MHz, there was an appreciable divergence of the received signal strength from the model.

Another experiment was performed in the Missouri River where the results of Table 12 where obtained. These results are plotted in Figure 7.

| Distance (feet) | Transmitted Signal Strength (dBm) | Received Signal Strength (dBm) |
|---|---|---|
| 6 | 10 | -65 |
| 8 | 10 | -75 |
| 10 | 10 | -78 |
| 12 | 10 | -90 |
| 15 | 10 | -90 |

*Table 12: 150 MHz RF Measurements in Missouri River, Cond.=766µS/cm, Temp=22.7°C*

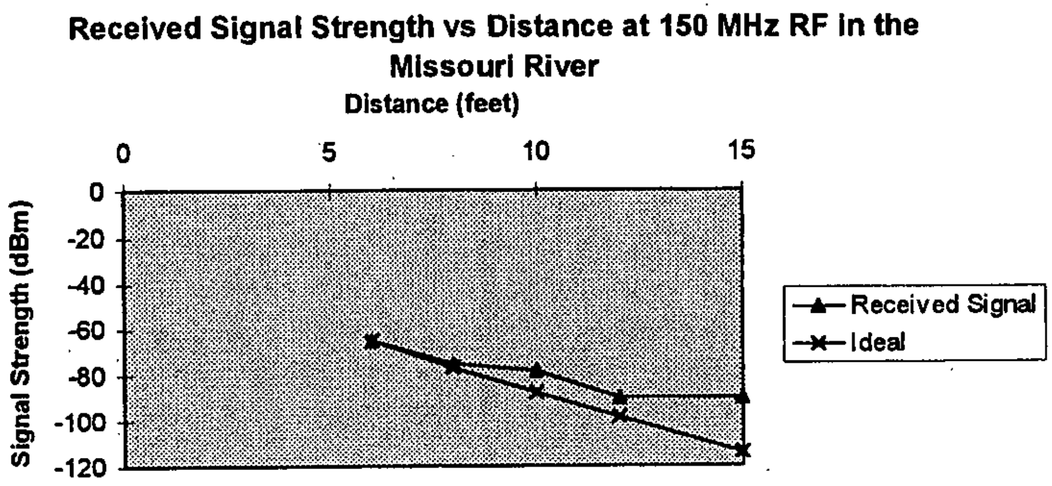


*Figure 7*

The observed divergence of the received signal strength from the predicted signal strength at 150 MHz also fits the theory of reception through air. An experiment in the MSC pond could again confirm this. The results of the 150 MHz pond experiment are shown in Table 13.

| Distance (feet) | Transmitted Signal Strength (dBm) | Received Signal Strength (dBm) |
|---|---|---|
| 5.0 | 10 | -48 |
| 10.1 | 10 | -62 |
| 15.0 | 10 | -90 |

*Table 13: 150 MHz RF Measurements in Pond, Cond.=591$\mu$S/cm, Temp=16.2℃*

The plot of this data showed an appreciable improvement in agreement with the model as shown in Figure 8.

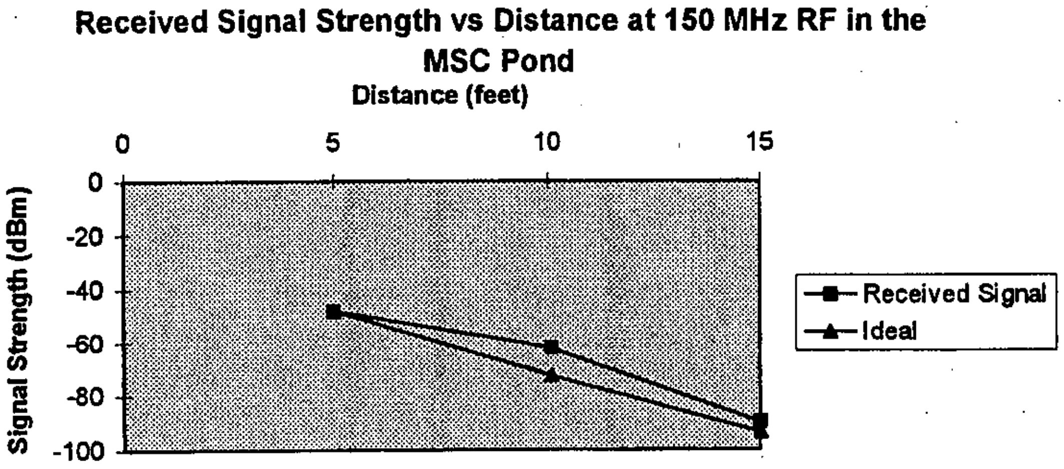


*Figure 8*

A linear regression analysis shows that the loss exhibited by the data was 13.7 dB/m whereas the model predicted 11.82 dB/m. Although these results are not as closely matched as those at 50 MHz, the model is still more conservative and acceptable.

### *5.1.5. Noise Level*

Impulsive noise from the AC generator was quite prevalent at 50 MHz reaching levels of -70 dBm and higher which would be very effective in reducing receiver sensitivity. At 150 MHz noise was below -100 dBm. As a result, one could expect an additional 30 dB improvement in range over 50 MHz in such an environment.

Interference from other sources (machinery, transmitters, etc.) was not encountered during the experiments, however, a survey of noise sources throughout the entire study area should be performed on any proposed frequencies before they are employed.

## 5.2. Ultrasonic

The following are the results obtained through experimentation at ultrasonic frequencies.

### *5.2.1. Frequency Response of Test System*

To aid in the analysis of the Ultrasonic measurements, it was necessary to confirm the frequency response of the test system. At a fixed distance of 25 feet, a change in signal strength with frequency was observed. These observations are shown in Table 14.

| Frequency (kHz) | Response (dB) |
|---|---|
| 32 | -11 |
| 42 | -2 |
| 52 | -1 |
| 62 | -6 |
| 72 | 0 |
| 82 | -17 |
| 92 | -15 |
| 102 | -2 |

*Table 14: Measured Frequency Response of System*

When plotted along with the data provided by Vemco on the response of the hydrophone and projector, it is obvious that there is a significant variation due to equipment, mostly the transducers (Figure 9). Unfortunately, Vemco did not provide a complete sweep response, therefore, it is necessary to estimate between and extrapolate beyond these points.

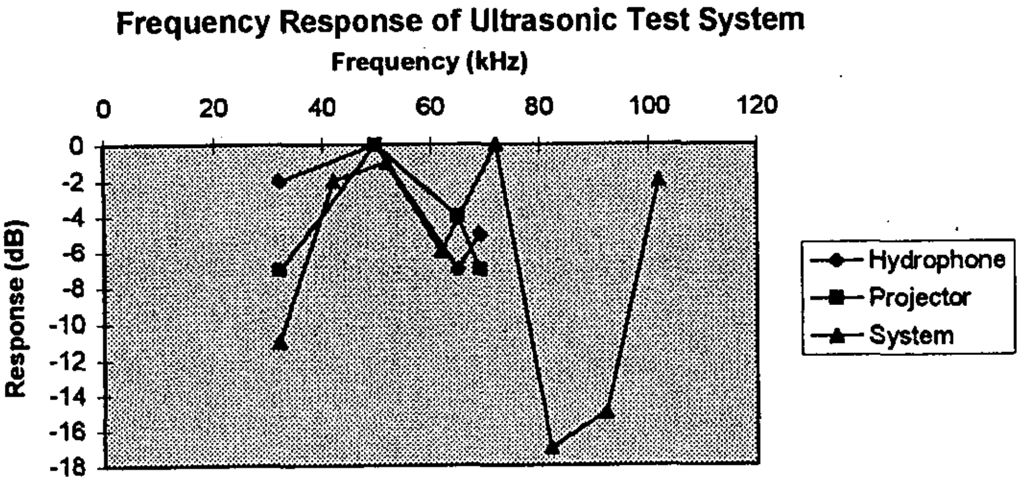


*Figure 9*

There is some discrepancy between the system response measured and the response attributable to the transducers especially near 70 kHz. Although the hydrophone shows a slight improvement, it hardly offsets the fall off of the projector response. Since the signal generator and spectrum analyzer calibration were verified, this could only be attributed to propagation anomalies (interference patterns) or inaccurate transducer calibration data.

### *5.2.2. 32 kHz Ultrasonic Measurements*

Ultrasonic experiments are easier than RF experiments to control since radiation through the air is not a factor. Ultrasonic signals will remain predominantly confined below the water surface. As with the RF experiments, the goal was to measure the received signal strength at various distances to determine the actual loss per meter and compare it to the ultrasonic model.

Ultrasonic measurements at 32 kHz were carried out in two locations, Perche Creek and the MSC pond. The results are shown in Table 15: 32 kHz Ultrasonic Measurements in Perche Creek and Table 16: 32 kHz Ultrasonic Measurements in Pond.

| **Distance (feet)** | **Transmitted Signal Strength (dBm @ 50Ω)** | **Received Signal Strength (dBm @ 50Ω)** |
|---|---|---|
| 100 | 8 | -42 |
| 200 | 8 | -50 |

*Table 15: 32 kHz Ultrasonic Measurements in Perche Creek*

| **Distance (feet)** | **Transmitted Signal Strength (dBm @ 50Ω)** | **Received Signal Strength (dBm @ 50Ω)** |
|---|---|---|
| 5 | 8 | -17 |
| 10 | 8 | -30 |
| 15 | 8 | -28 |
| 25 | 8 | -29 |
| 50 | 8 | -45 |
| 100 | 8 | -60 |

*Table 16: 32 kHz Ultrasonic Measurements in Pond*

To conform to standard units used in sonar, the measurements were converted using the formulas derived earlier. The results of these calculations are shown in Table 17 and Table 18

| **Distance (feet)** | **Source Level (dBμPa @ 1m)** | **Received Signal Strength (dBμPa)** |
|---|---|---|
| 100 | 121 | 107 |
| 200 | 121 | 99 |

*Table 17: Calculated 32 kHz Ultrasonic Signal Strengths in Perche Creek*

| Distance (feet) | Source Level (dBµPa @ 1m) | Received Signal Strength (dBµPa) |
|---|---|---|
| 5 | 121 | 132 |
| 10 | 121 | 119 |
| 15 | 121 | 121 |
| 25 | 121 | 120 |
| 50 | 121 | 104 |
| 100 | 121 | 89 |

*Table 18: Calculated 32 kHz Ultrasonic Signal Strengths in Pond*

These values, when plotted, exhibit a trend very similar to the model, however, they differ in a few significant ways (Figure 10). In the MSC pond, the signal strength begins and remains stronger than predicted actually increasing momentarily with distance before falling off rapidly. In Perche Creek, the decrease in signal strength with distance was much more gradual closely matching the slope of the model curve but stronger by about 18 dB.

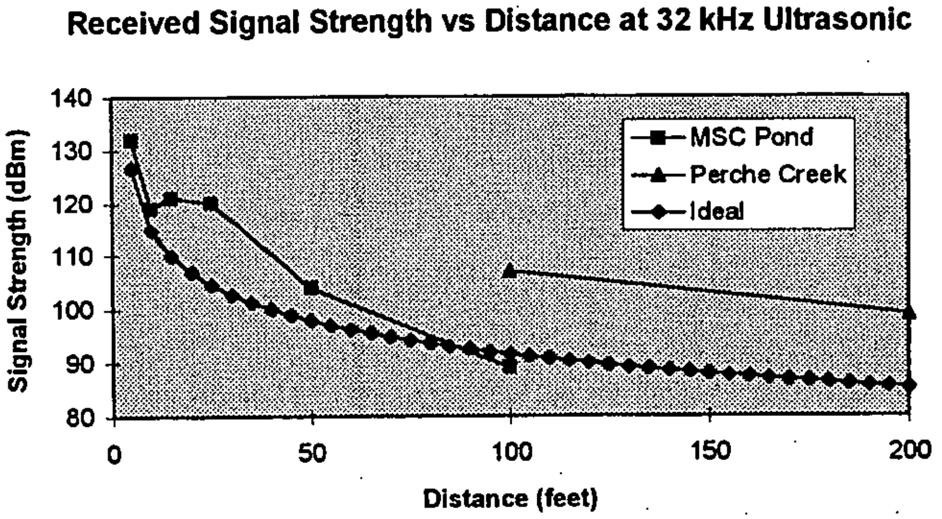


*Figure 10*

The matching slope of the Perche Creek curve suggests that the model may be correct but calibration is off (as suspected from the system response curve). If the model curve were shifted upwards by 18 dB it would closely match the results obtained over the initial few feet in the MSC pond as well as in Perche Creek. The rapid decrease in signal strength observed in the pond could then be attributed to the large amount plant growth observed there.

### *5.2.3. 69 kHz Ultrasonic Measurements*

At 69 kHz, experiments were performed in Perche Creek, the Missouri River and in the MSC pond. These results are shown in Table 19, Table 20 and Table 21.

| Distance (feet) | Transmitted Signal Strength (dBm @ 50Ω) | Received Signal Strength (dBm @ 50Ω) |
|---|---|---|
| 75 | 8 | -40 |
| 100 | 8 | -42 |
| 200 | 8 | -50 |

*Table 19: 69 kHz Ultrasonic Measurements in Perche Creek*

| Distance (feet) | Transmitted Signal Strength (dBm @ 50Ω) | Received Signal Strength (dBm @ 50Ω) |
|---|---|---|
| 50 | 8 | -37 |
| 75 | 8 | -38 |
| 100 | 8 | -40 |

*Table 20: 69 kHz Ultrasonic Measurements in Missouri River*

| Distance (feet) | Transmitted Signal Strength (dBm @ 50Ω) | Received Signal Strength (dBm @ 50Ω) |
|---|---|---|
| 5 | 8 | -23 |
| 10 | 8 | -24 |
| 15 | 8 | -26 |
| 25 | 8 | -28 |
| 50 | 8 | -40 |
| 100 | 8 | -55 |

*Table 21: 69 kHz Ultrasonic Measurements in Pond*

Conversion to standard sonar units yields the values in Table 22, Table 23, and Table 24.

| Distance (feet) | Source Level (dBµPa @ 1m) | Received Signal Strength (dBµPa) |
|---|---|---|
| 75 | 121 | 112 |
| 100 | 121 | 110 |
| 200 | 121 | 102 |

*Table 22: Calculated 69 kHz Ultrasonic Signal Strengths in Perche Creek*

| Distance (feet) | Source Level (dBµPa @ 1m) | Received Signal Strength (dBµPa) |
|---|---|---|
| 50 | 121 | 115 |
| 75 | 121 | 114 |
| 100 | 121 | 112 |

*Table 23: Calculated 69 kHz Ultrasonic Signal Strengths in Missouri River*

| Distance (feet) | Source Level (dBµPa @ 1m) | Received Signal Strength (dBµPa) |
|---|---|---|
| 5 | 121 | 129 |
| 10 | 121 | 128 |
| 15 | 121 | 126 |
| 25 | 121 | 124 |
| 50 | 121 | 112 |
| 100 | 121 | 97 |

*Table 24: Calculated 69 kHz Ultrasonic Signal Strengths in Pond*

The plots of these results are very similar to those for 32 kHz where the signal strengths are generally 18 dB stronger, matching the slope of the model curve in deeper water such as Perche Creek and the Missouri River, but attenuating rapidly at larger distances in the MSC pond (Figure 11).

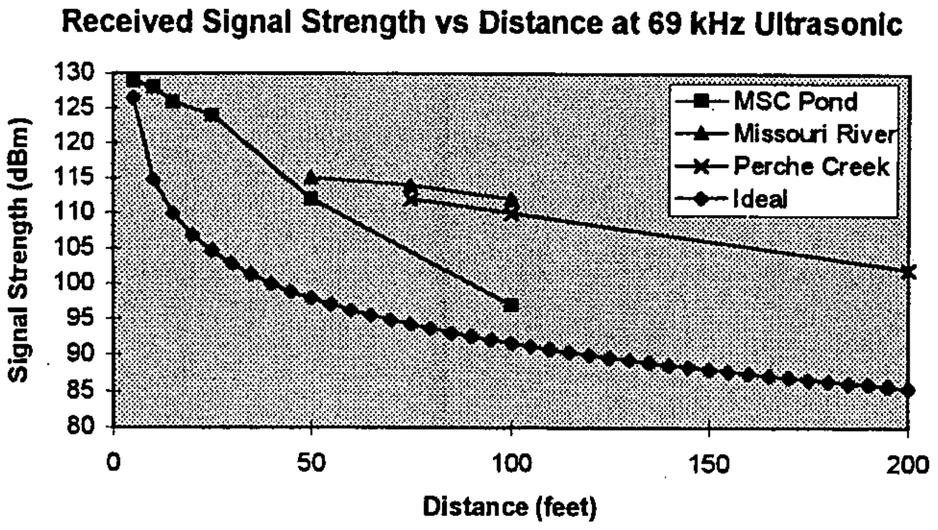


*Figure 11*

The consistency of these results as compared to 32 kHz add credence to the idea that the anomalies are due to a calibration error and attenuation by plants in the pond as opposed to human error.

### *5.2.4. Source Level Measurements of Sample Transmitters*

Several sample transmitters were on hand for experimentation. One was manufactured by Vemco and three others were manufactured by Sonotronics. Table 25: Sample Transmitters shows the frequencies involved.

| **Transmitter** | **Frequency (MHz)** |
|---|---|
| Vemco | 54.0 |
| Sonotronics (339) | 76.8 |
| Sonotronics (276) | 76.4 |
| Sonotronics (357) | 73.9 |

*Table 25: Sample Transmitters*

Assuming the signal generator/projector combination is calibrated, the source level produced by the projector can be accurately calculated. By comparing the signal levels from the transmitters to that from the signal generator and projector, the relative signal strengths can be measured and, thus, the source level of the transmitters can be determined.

Table 26 shows the signal strengths as measured on the spectrum analyzer.

| **Transmitter** | **Transmitter Signal Strength (dBm @ 50Ω)** | **Reference Signal Strength (dBm @ 50Ω)** | **Difference (dB)** |
|---|---|---|---|
| Vemco | -16 | -25 | 9 |
| Sonotronics (339) | -32 | -38 | 6 |
| Sonotronics (276) | -32 | -38 | 6 |
| Sonotronics (357) | -30 | -36 | 6 |

*Table 26: Signal Strength Measurements of Transmitters and Reference at 25 feet*

The source level of the projector is calculated for reference to the Vemco transmitter by choosing the formula derived previously using the parameter which is closest in frequency. Unfortunately, hydrophone and projector data is not provided above 69 kHz to match the Sonotronics transmitter frequencies. Since the system response suggests significantly degraded performance above 72 kHz, it is hard to tell if this is due to the hydrophone or projector or a combination of both. As a result, it is difficult to tell if a positive or negative offset should be applied to the transmitter signal strength.

Assuming that the majority of system performance degradation (say 10 dB) is attributed to the hydrophone and the remainder (3 dB) is attributed to the projector, the source level of the signal generator at the Sonotronics frequencies can be estimated. This does not produce a completely fair evaluation but it does give an estimate of the relative performances under the circumstances. The possibility that the majority of the loss is attributable to the hydrophone is suggested by the noise response exhibited later.

Table 27 contains the resulting calculated source levels.

| Transmitter | Calculated Source Level of Reference (dBµPa @ 1m) | Difference Measured (dB) | Source Level of Transmitter (dBµPa @ 1m) |
|---|---|---|---|
| Vemco | 128 | 9 | 137 |
| Sonotronics (339) * | 125 | 6 | 131 |
| Sonotronics (276) * | 125 | 6 | 131 |
| Sonotronics (357) * | 125 | 6 | 131 |

** uncalibrated estimate*

*Table 27: Calculated Source Levels of Sample Transmitters*

Literature on the Vemco transmitters suggests that the source level should be 153 dBµPa @ 1m which is much higher than the measured 137 dBµPa @ 1m. If there is indeed an 18 dB calibration error, then the actual source levels would be equivalent to those in Table 28.

| Transmitter | Calculated Source Level of Reference (dBµPa @ 1m) | Difference Measured (dB) | Source Level of Transmitter (dBµPa @ 1m) |
|---|---|---|---|
| Vemco | 146 | 9 | 155 |
| Sonotronics (339) * | 143 | 6 | 149 |
| Sonotronics (276) * | 143 | 6 | 149 |
| Sonotronics (357) * | 143 | 6 | 149 |

** uncalibrated estimate*

*Table 28: Calculated Source Levels of Sample Transmitters offset by Error Estimate*

As a result, the actual source level of the Vemco transmitter matches more closely that of the literature at 155 dBµPa @ 1m. This discrepancy should be investigated.

### 5.2.5. Noise Level

The final environmental parameter that affects the sonar equation is the background noise level. Measurements of background noise were made within a large L shaped wing dike (Location 1), outside the wing dike (Location 2), and near a submerged wing dike (Location 3). The noise levels displayed on the spectrum analyzer were high at low frequencies, falling off to a minimum at 82 kHz, and rising to another peak at about 102 kHz. The values measured are shown in Table 29.

|  | Location 1 | Location 2 | Location 3 |
|---|---|---|---|
| **32 kHz** | -70 | -50 | -45 |
| **52 kHz** | -70 | -45 | -40 |
| **82 kHz** | -88 | -63 | -56 |
| **102 kHz** | -77 | -45 | -40 |

*Table 29: Measured Noise Levels (dBm @ 50Ω/1kHz)*

Conversion using the equation derived earlier for the hydrophone and estimates obtained from the system response curve, produce the values given in Table 30.

| | **Location 1** | **Location 2** | **Location 3** |
|---|---|---|---|
| **32 kHz** | 49 | 69 | 74 |
| **52 kHz** | 47 | 72 | 77 |
| **82 kHz *** | 45 | 70 | 77 |
| **102 kHz *** | 41 | 73 | 78 |

** uncalibrated estimate*

*Table 30: Calculated Noise Levels (dBμPa/Hz)*

Understandably, the background noise in location 1 was quite low since it was a protected area with calm water. Location 2, however, was much noisier as water was rushing along the wing dikes and around eddies. Location 3 was slightly noisier still as water was disturbed greatly in rapids above the submerged wing dike.

The noise showed very little frequency dependence once corrected. Any differences observed were within the expected error of 5 dB or outside the calibrated range.

### *5.2.6. Ultrasonic Model Calculations*

Since experiments suggested a lack of frequency dependence in both transmission loss and background noise and since the background noise was consistent within the Missouri River, there appears to be little probable variation in ultrasonic performance due to the environment. As a result, the best, average and worst case conditions are essentially the same. Using the results obtained for noise levels within the Missouri and the corrected sample transmitter outputs, the ultrasonic model can be used to estimate range. An assumption of receiver integration time, bandwidth and detection index must be made to determine the detection threshold. Reasonable estimates produce a detection threshold of approximately 28 dB.

Appendix E shows the worksheets for these calculations. The predicted range for the Vemco transmitter is approximately 500 m whereas the predicted range for the Sonotronics transmitters is 250 m. A 500 m range was observed with the Vemco transmitters, thus supporting the 18 dB correction factor applied to the measured transmitter source levels and the model in general.

The 250 m range estimate for the Sonotronics transmitters was not confirmed and the range estimate is somewhat questionable since the transmitter source levels are not accurately known. These results do, however, underline the need to carefully select products for the environment as a 500 m range will work well but a 250 m range will not.

## 6. CONCLUSIONS

During the experiments it became clear, especially under adverse weather conditions, that it would be difficult to control the boats which were to be used as platforms for the test equipment. Results were adversely affected by the ability to control the position of the boats and the reception of RF signals through the air. The concept of measuring RF attenuation at each of the best, average and worst case locations was abandoned in favour of measurements in the Midwest Science Center pond only.

RF measurements made within the pond matched the predicted values very closely, thus reinforcing the validity of the RF system model.

Performance using RF telemetry will be very poor, especially since even the best conditions will not yield detection to the depths expected for sturgeon.

Ultrasonic experiments revealed consistent losses regardless of location. These results closely followed those predicted using the ultrasonic system model however an 18 dB offset was observed. This offset could be attributed to interference patterns or improper calibration parameters. Improper calibration parameters are suspect since measurement of the Vemco transmitter source level was 16 dB below specification.

Ultrasonic performance was limited primarily by the noise level experienced in the Missouri River. Noise will have to be controlled by careful mounting of hydrophones and careful boating. Motoring downstream would minimize current around the hydrophone and increase performance.

Although ultrasonic technology can work for pallid sturgeon study, its success depends largely on the power output of the transmitters used. Care will have to be taken to source the most powerful transmitter and ensure all transmitters delivered meet a minimum power specification.

# 7. RECOMMENDATIONS

Since the RF model used to predict performance at various frequencies, conductivities, and temperatures holds up rather well under the practical measurements made, continued use is recommended for predicting system performance under other conditions.

RF telemetry should not be used in the Missouri River for studies of bottom dwelling fish such as the pallid sturgeon since the detection depths will not be great enough even under the best conditions.

Since there is some uncertainty with respect to the ultrasonic calibration, further investigation of the response of the projector and hydrophone is required prior to future calibrated measurements.

Ultrasonic telemetry should be used in the Missouri River for studies of bottom dwelling fish such as pallid sturgeon as detection at expected river depths is probable. Vendor equipment should be carefully chosen to satisfy range estimates.

The ultrasonic model can be used cautiously to predict the range of various ultrasonic systems in the Missouri River using the noise levels measured. In fact, the model appears to be conservative about its estimate. This estimate should be used in the selection of vendor equipment. Further verification of chosen equipment with calibrated practical measurements is recommended.

# A. ATTENUATION IN WATER

The attenuation in water is evaluated using the equation for the electric field intensity of a plane wave propagating in the direction of $\bar{z}$. The electric field intensity at the distance $z$ given by:

$$E(z) = E_0 e^{-\gamma z}$$

where ,

$E_0$ is the electric field intensity at $z = 0$

$\gamma$ is the propagation constant of the medium

Since the power density is related to the electric field by the equation

$$S = \frac{E^2}{Z_0}$$

it follows that

$$S(z) = S_0 e^{-2\gamma z}$$

Now $\gamma$ is the propagation constant of the medium and it is evaluated using the equation

$$\gamma = \alpha + j\beta$$

where,

$\alpha$ is the absorption constant
$\beta$ is the phase constant

Since we are concerned only with the losses in brackish water, we can ignore the phase component of the power density equation giving us

$$|S(z)| = |S_0| e^{-2\alpha z}$$

The power absorption coefficient $\kappa_a$ is defined as

$$\kappa_a = 2\alpha$$

Therefore, the ratio of the power at distance $z$ to the original power can be expressed as

$$\frac{|S(z)|}{|S_0|} = e^{-\kappa_a z}$$

Expressing this power ratio in decibels gives

$$\frac{|S(z)|}{|S_0|} \text{ dB} = 10\log(e^{-\kappa_a z})$$

$$= -\kappa_a z(10\log e)$$

$$= -4.34\kappa_a z$$

Or, in terms of loss

$$L_w \text{ dB} = -\frac{|S(z)|}{|S_0|}$$

$$= 4.34\kappa_a z$$

By taking the derivative with respect to distance, the loss per meter is determined:

$$\frac{dL_w}{dz} \text{ dB} = 4.34\kappa_a$$

Now, to determine $\kappa_a$, we must determine $\alpha$. $\alpha$ is related to the wave number in free space, $k_0$, and the index of refraction, $n$, with the equation:

$$\alpha = k_0 n'' \ \tfrac{\text{Np}}{\text{m}}$$

where $k_0$ is related to the free space wavelength, $\lambda_0$, by the equation:

$$k_0 = \frac{2\pi}{\lambda_0}$$

and

$$\lambda_0 = \frac{3\times10^8}{f}$$

$n''$ is the imaginary component of the index of refraction where,

$$n = n' - jn''$$

The index of refraction can be determined from the average relative dielectric constant:

$$n^2 = \varepsilon$$

The dielectric constant can also have both real and imaginary components:

$$\varepsilon = \varepsilon' - j\varepsilon''$$

They can be shown to be related to the real and imaginary components of the index of refraction by the equations,

$$n' = \text{Re}\{\sqrt{\varepsilon}\}$$

$$n'' = |\text{Im}\{\sqrt{\varepsilon}\}|$$

In pure water, the frequency dependence of the dielectric constant is given by the Debye equation:

$$\varepsilon_w = \varepsilon_{w\infty} + \frac{\varepsilon_{w0} - \varepsilon_{w\infty}}{1 + j2\pi f\tau_w}$$

where,

$\varepsilon_{w0}$ is the static dielectric constant of pure water (dimensionless)
$\varepsilon_{w\infty}$ is the high frequency or optical limit of $\varepsilon_w$ (dimensionless)
$\tau_w$ is the relaxation time of pure water
$f$ is the frequency of the electromagnetic wave (Hz)

This equation can be rationalized into real and imaginary components as follows:

$$\varepsilon'_w = \varepsilon_{w\infty} + \frac{\varepsilon_{w0} - \varepsilon_{w\infty}}{1 + (2\pi f\tau_w)^2}$$

$$\varepsilon''_w = \frac{2\pi f\tau_w(\varepsilon_{w0} - \varepsilon_{w\infty})}{1 + (2\pi f\tau_w)^2}$$

In saline water, these equations become,

$$\varepsilon'_{sw} = \varepsilon_{sw\infty} + \frac{\varepsilon_{sw0} - \varepsilon_{sw\infty}}{1 + (2\pi f\tau_{sw})^2}$$

$$\varepsilon''_{sw} = \frac{2\pi f\tau_{sw}(\varepsilon_{sw0} - \varepsilon_{sw\infty})}{1 + (2\pi f\tau_{sw})^2} + \frac{\sigma_i}{2\pi\varepsilon_0 f}$$

The high frequency limit of the dielectric constant has been found empirically by Lane and Saxton (1952) to be,

$$\varepsilon_{w\infty} = 4.9$$

There has been some controversy over the dependence of $\varepsilon_{w\infty}$ on temperature, however, this dependence is so weak that it can be considered constant in these equations.

The relaxation time of pure water is,

$$\tau_w(T) = \frac{1.1109 \times 10^{-10} - 3.824 \times 10^{-12} T + 6.938 \times 10^{-14} T^2 - 5.096 \times 10^{-16} T^3}{2\pi}$$

which is related to the often used term "relaxation frequency" which is,

$$f_0 = \frac{1}{2\pi\tau}$$

The static dielectric constant of pure water between 0 and 100 degrees Celsius was found empirically by Malmberg and Maryott (1956) and later refined by Klein and Swift (1977) to give the equation,

$$\varepsilon_{w0}(T) = 88.045 - 0.4147T + 6.295 \times 10^{-4} T^2 + 1.075 \times 10^{-5} T^3$$

$\varepsilon_0$ is the permittivity of free space which is,

$$\varepsilon_0 = 8.854 \times 10^{-12} \tfrac{F}{m}$$

Stogryn (1971) pointed out that there is no evidence that the high frequency limit of the dielectric constant varies with salinity, therefore,

$$\varepsilon_{sw\infty} = \varepsilon_{w\infty} = 4.9$$

Klein and Swift (1977) produced polynomial fits from data measured by Ho and Hall (1973) and Ho et al. (1974) for salinities in the range $4 \leq S_{sw} \leq 35$ ‰. This is outside of the range expected for fresh water streams and rivers (assumed to be less than 1), however, due to the lack of any other data, we will use the equations here.

It is stated that,

$$\varepsilon_{sw0}(T,S_{sw}) = \varepsilon_{sw0}(T,0) \cdot a(T,S_{sw})$$

where,

$$\varepsilon_{sw0}(T,0) = 87.134 - 1.949 \times 10^{-1} T - 1.276 \times 10^{-2} T^2 + 2.491 \times 10^{-4} T^3$$

$$a(T,S_{sw}) = 1.0 + 1.613 \times 10^{-5} T S_{sw} - 3.656 \times 10^{-3} S_{sw} + 3.210 \times 10^{-5} S_{sw}^2 - 4.232 \times 10^{-7} S_{sw}^3$$

Similar equations were developed by Stogryn (1971) and Klein and Swift (1977) from data produced by Grant et al. (1957) to describe the variation of relaxation time with temperature and salinity:

$$\tau_{sw}(T,S_{sw}) = \tau_w(T) \cdot b(T,S_{sw})$$

where $\tau_w(T)$ is as previously described and,

$$b(T,S_{sw}) = 1.0 + 2.282 \times 10^{-5} T S_{sw} - 7.638 \times 10^{-4} S_{sw} - 7.760 \times 10^{-6} S_{sw}^2 + 1.105 \times 10^{-8} S_{sw}^3$$

The above equation is valid over the range $0 \leq T \leq 40$ °C and $0 \leq S_{sw} \leq 157$ ‰.

The ionic conductivity was derived by Weyl (1964) and later modified by Stogryn (1971) to the form,

$$\sigma_i(T,S_{sw}) = \sigma_i(25,S_{sw}) e^{-\phi}$$

where the ionic conductivity of saline water at 25 °C is given by,

$$\sigma_i(25,S_{sw}) = S_{sw}(0.18252 - 1.4619 \times 10^{-3} S_{sw} + 2.093 \times 10^{-5} S_{sw}^2 - 1.282 \times 10^{-7} S_{sw}^3)$$

$\phi$ depends on $S_{sw}$ and $\Delta$ as follows,

$$\phi = \Delta[2.033 \times 10^{-2} + 1.266 \times 10^{-4} \Delta + 2.464 \times 10^{-6} \Delta^2 - S_{sw}(1.849 \times 10^{-5} - 2.551 \times 10^{-7} \Delta + 2.551 \times 10^{-8} \Delta^2)]$$

where,

$$\Delta = 25 - T$$

These equations are valid for $0 \leq S_{sw} \leq 40$ ‰.

## B. VEMCO PRODUCT INFORMATION

VEMCO Limited, 3895 Shad Bay Rd, RR#4 Armdale, NS, Canada, B3L 4J4
Phone: 902-852-3047 Fax: 902-852-4000

Mr. Cam Grant

**FAX:** (905) 836-8365

**CALIBRATED HYDROPHONE:** VH 65

Output Impedance: 75 ohms

| Frequency | Hydrophone sensitivity: VH-65; SN=1087 dB re 1 volt / uPascal |
|---|---|
| 32 | -154 |
| 50 | -152 |
| 65 | -159 |
| 69 | -157 |

**POTTED CERAMIC (PROJECTOR):** VH65 - no amp.

| | |
|---|---|
| Red wire | Centre of ceramic. |
| Blue wire | Outside of ceramic |
| Shield | Unconnected. |

Impedance: 9.5 nf in parallel with 2k

| Frequency | Peak to peak Voltage | Potted Element Acoustic Power Output dB re 1 uPascal @ 1Meter |
|---|---|---|
| 32 | 10 vptp | 137 |
| 50 | 10 vptp | 144 |
| 65 | 10 vptp | 140 |
| 69 | 10 vptp | 137 |

VR-60 input impedance: 2k

**V16 SERIES** ***Small size, 16mm diameter. Our most popular fish tracking series.***

Frequencies: 50.0, 54.0, 60.0, 65.5, 69.0, 76.8 kHz
BI-CYCLE and DELAYED START options available
Pulse Rate: Fixed Pinger or linearly proportional to sensor output.
Sensors Available: Depth, Temperature, Heart Rate.
Pressure Sensors: 15, 50, 100, 200, 300, 500, 1000 PSI [100 PSI = 68 Meter Depth Salt Water]
Used with V-10 directional hydrophone, VR-60 or VR20 receivers.

| 16MM DIA | | SILVER OXIDE BATTERIES | | | | | | LITHIUM BATTERIES | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PART NUMBER | | -1L | -1H | -2L | -2H | -3L | -3H | -4L | -4H | -5L | -5H | -6L | -6H | Power Suffix |
| V16 | Length | 48 | 48 | 52 | 52 | 58 | 58 | 65 | 65 | 92 | 92 | 90 | 90 | Millimetres |
| | Weight | 9 | 9 | 10 | 10 | 11 | 11 | 10 | 10 | 16 | 16 | 14 | 14 | Grams in $H_2O$ |
| | Life | 44 | 20 | 34 | 12 | 26 | 11 | 268 | 111 | 150 | 65 | 476 | 198 | Days @ 1 Hz |
| V16P | Length | 62 | 62 | | | 74 | 74 | 80 | 80 | 108 | 108 | 106 | 106 | Millimetres |
| | Weight | 9 | 9 | | | 14 | 14 | 12 | 12 | 18 | 18 | 15 | 15 | Grams in $H_2O$ |
| | Life | 19 | 12 | | | 16 | 9 | 89 | 60 | 110 | 58 | 178 | 112 | Days @ 1Hz |
| V16T | Length | 62 | 62 | | | 74 | 74 | 80 | 80 | 108 | 108 | 106 | 106 | Millimetres |
| | Weight | 9 | 9 | | | 14 | 14 | 12 | 12 | 18 | 18 | 16 | 16 | Grams in $H_2O$ |
| | Life | 19 | 12 | | | 18 | 9 | 89 | 60 | 110 | 58 | 178 | 112 | Days @ 1 Hz |
| POWER OUT | | 146 | 152 | 149 | 155 | 152 | 158 | 147 | 153 | 153 | 159 | 147 | 153 | dB re 1uP @ 1M |

Users of the old version V3 transmitters will notice significant battery life increases in the above table. This is particularly evident in data telemetry types such as the V3P series. The reason for the increase in life is due to our new "Intelligent" tag circuitry which applies power to the sensor circuits only during measurements, and also due to improvements in battery chemistry. Note that battery life values shown are for the baseline of one acoustic pulse per second, significant improvements can be made by applying BI-CYCLE and DELAYED ACTIVATION options.
The two graphs below indicate battery life extensions achievable with BI-CYCLE and DELAY START options on two V16 series transmitters. Because it is not practical to include graphs for every type of transmitter in this catalog we present these as examples. Please contact us for more data on the transmitter of your choice.

## *CODING SCHEMES USED FOR DATA TELEMETRY TYPES*

The single channel types T and P use LINEAR INTERVAL CODING as described in Sec 4.4.1 of the "Quick Course in Underwater Telemetry Systems". Our standard pulse rate variation is from 1000 mSec to 1510 mSec with positive slope. This means that a pressure transmitter will output 1000 mSec pulses on the surface increasing to 1510 mSec at full scale depth.

The dual channel types TP use dual channel LINEAR INTERVAL CODING as described in section 4.4.2. This code uses a fixed synchronization interval followed by two data intervals representing Temperature and Depth.

Both single and dual channel types can be decoded by the VR-60 receiver. For the dual types the display will show depth data and temperature data at the same time using different lines on the display. All data telemetry transmitters are provided with calibration graphs and decoding constants.

## C. WATER QUALITY DATA

## GASCONADE RIVER BASIN

### 06930800 GASCONADE RIVER ABOVE JEROME, MO
(National stream-quality accounting network station)

### WATER-QUALITY RECORDS

LOCATION.—Lat 37°55'12", long 91°58'33", in NE ¼ sec.24, T.37 N., R.10 W., Phelps County, Hydrologic Unit 10290203, at bridge on County Highway D at Jerome, 150 ft upstream from Little Piney Creek, 0.7 mi upstream from gaging station.

DRAINAGE AREA.—2,570 mi$^2$.

PERIOD OF RECORD.—January 1978 to current year.

PERIOD OF DAILY RECORD.—
Specific Conductance: March 1978 to September 1981.
Water Temperature: March 1978 to September 1981.

EXTREMES FOR PERIOD OF DAILY RECORD.—
Specific Conductance: Maximum Daily, 588 microsiemens, Sept. 23, 1981; minimum daily, 133 microsiemens, Sept. 1, 1981.
Water Temperature: Maximum daily, 34.0° C, Aug 11 and 17, 1980; minimum daily, 0.0° C on many days during winter period.

### WATER-QUALITY DATA, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

| DATE | TIME | DISCHARGE, INST. CUBIC FEET PER SECOND (00061) | SPECIFIC CONDUCT-ANCE (US/CM) (00095) | PH WATER WHOLE FIELD (STAN-DARD UNITS) (00095) | TEMP-ERATURE WATER (DEG C) (00010) | TURBID-ITY (NTU) (00076) | OXYGEN, DISSOLVED (MG/L) (00300) | OXYGEN, DISSOLVED (PERCENT SATURATION) (00301) | HARDNESS TOTAL (MG/L AS CACO3) (00900) | ALKALINITY WAT DIS TOT IT FILED MG/L AS CACO3 (39086) |
|---|---|---|---|---|---|---|---|---|---|---|
| NOV 06 | 1330 | 2110 | 293 | 8.0 | 7.0 | 8.4 | 10.4 | 85 | 160 | 144 |
| JAN 10 | 1130 | 1530 | 319 | 8.2 | 6.5 | 1.5 | 11.3 | 89 | 1170 | 157 |
| MAR 02 | 1000 | 1610 | 309 | 8.1 | 11.5 | 2.4 | 11.1 | 100 | 170 | 148 |
| MAY 07 | 1430 | 1450 | 302 | 8.3 | 17.5 | 3.5 | 10.5 | 107 | 170 | 141 |
| JUL 06 | 1410 | 922 | 329 | 8.1 | 25.0 | 2.0 | 8.3 | 100 | 170 | 178 |
| SEP 04 | 1030 | 589 | 345 | 6.7 | 22.5 | 0.8 | 8.2 | 93 | 180 | 182 |

# OSAGE RIVER BASIN

## 06926510 OSAGE RIVER BELOW ST. THOMAS, MO
(National stream-quality accounting network station)

## WATER-QUALITY RECORDS

LOCATION.—Lat 38°25'18", long 92°12'31", in NW ¼ NW ¼ sec.1, T.42 N., R.12 W., Cole County, Hydrologic Unit 10290111, at bridge on State Highway B, 3.8 mi north of St. Thomas, 8.6 mi downstream from gaging station and at mile 34.5.

DRAINAGE AREA.—14,500 mi² approximately.

PERIOD OF RECORD.—Water year 1975 to current year.

PERIOD OF DAILY RECORD.—

Specific Conductance: October 1974 to September 1981.
Water Temperature: October 1974 to September 1981.

EXTREMES FOR PERIOD OF DAILY RECORD.—

Specific Conductance: Maximum Daily, 398 microsiemens, Jan. 1, 1981; minimum daily, 140 microsiemens, Sept. 3, 1981.
Water Temperature: Maximum daily, 30.0° C, July 29, 1977, July 25, and Aug. 11, 1980; minimum daily, 0.0° C, Jan. 21, 1978.

## WATER-QUALITY DATA, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

| DATE | TIME | DISCHARGE, INST. CUBIC FEET PER SECOND (00061) | SPECIFIC CONDUCT-ANCE (US/CM) (00095) | PH WATER WHOLE FIELD (STAN-DARD UNITS) (00095) | TEMP-ERATURE WATER (DEG C) (00010) | TURBID-ITY (NTU) (00076) | OXYGEN, DISSOLVED (MG/L) (00300) | OXYGEN, DISSOLVED (PERCENT SATURATION) (00301) | HARDNESS TOTAL (MG/L AS CACO3) (00900) | ALKALINITY WAT DIS TOT IT FILED MG/L AS CACO3 (39086) |
|---|---|---|---|---|---|---|---|---|---|---|
| NOV 04 | 1015 | 2223 | 247 | 7.6 | 6.5 | 21 | 10.5 | 82 | 160 | -- |
| JAN 10 | 0930 | 4568 | 300 | 7.7 | 6.5 | 3.5 | 11.0 | 87 | 160 | 126 |
| MAR 04 | 1000 | 796 | 309 | 7.8 | 11.0 | 2.8 | 12.6 | 112 | 160 | 132 |
| MAY 04 | 1400 | 6086 | 299 | 7.9 | 17.5 | 1.5 | 10.1 | 103 | 160 | 134 |
| JUL 06 | 1200 | 6261 | 315 | 8.0 | 24.0 | 3.1 | 8.0 | 94 | 150 | 120 |
| SEP 04 | 0730 | 4970 | 289 | 6.9 | 24.0 | 3.0 | 5.7 | 66 | 140 | 118 |

## MISSOURI RIVER MAINSTEM

## 06934500 MISSOURI RIVER AT HERMANN, MO
(National stream-quality accounting network station)

## WATER-QUALITY RECORDS

PERIOD OF RECORD.—July 1969 to current year.

PERIOD OF DAILY RECORD.—
Specific Conductance: October 1974 to current year.
Water Temperature: October 1974 to current year.
Dissolved Oxygen: June 1984 to September 1984, April 1985 to September 1985, and April 1986 to September 1986.

INSTRUMENTATION.—Water quality monitor June 1984 to September 1984, April 1984 to September 1985, and April 1986 to September 1986.

REMARKS.—Water temperature and specific conductance samples collected daily by observer.

EXTREMES FOR PERIOD OF DAILY RECORD.—
Specific Conductance: (water years 1976 to current year): Maximum Daily, 2150 microsiemens, Dec. 9, 1978; minimum daily, 205 microsiemens, April 16, 1979.
Water Temperature: (water years 1976 to current year): Maximum daily, 32.5° C, July 31, 1987; minimum daily, 0.0° C on many days during winter period.

## WATER-QUALITY DATA, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

| DATE | TIME | DISCHARGE, INST. CUBIC FEET PER SECOND (00061) | SPECIFIC CONDUCT-ANCE (US/CM) (00095) | PH WATER WHOLE FIELD (STAN-DARD UNITS) (00095) | TEMP-ERATURE WATER (DEG C) (00010) | TURBID-ITY (NTU) (00076) | OXYGEN, DISSOLVED (MG/L) (00300) | OXYGEN, DISSOLVED (PERCENT SATURATION) (00301) | HARDNESS TOTAL (MG/L AS CACO3) (00900) | ALKALINITY WAT DIS TOT IT FILED MG/L AS CACO3 (39086) |
|---|---|---|---|---|---|---|---|---|---|---|
| NOV 04 | 1045 | 46100 | 614 | 8.3 | 6.5 | 42 | 12.0 | 96 | 220 | 161 |
| JAN 29 | 1200 | 34800 | 668 | 8.1 | 3.0 | 16 | 13.2 | 97 | 257 | 194 |
| MAR 02 | 1030 | 44500 | 532 | 8.2 | 8.5 | 55 | 11.4 | 97 | 210 | 156 |
| MAY 05 | 1000 | 71400 | 574 | 7.9 | 17.0 | 77 | 8.8 | 90 | 240 | 165 |
| JUL 16 | 1000 | 189000 | 476 | 7.5 | 24.5 | 500 | 4.0 | 47 | 170 | 129 |

## 06934500 MISSOURI RIVER AT HERMANN, MO
(National stream-quality accounting network station)

## WATER-QUALITY RECORDS

PERIOD OF RECORD.—July 1969 to current year.

PERIOD OF DAILY RECORD.—
Specific Conductance: October 1974 to current year.
Water Temperature: October 1974 to current year.
Dissolved Oxygen: June 1984 to September 1984, April 1985 to September 1985, and April 1986 to September 1986.

INSTRUMENTATION.—Water quality monitor June 1984 to September 1984, April 1984 to September 1985, and April 1986 to September 1986.

REMARKS.—Water temperature and specific conductance samples collected daily by observer.

EXTREMES FOR PERIOD OF DAILY RECORD.—
Specific Conductance: (water years 1976 to current year): Maximum Daily, 2150 microsiemens, Dec. 9, 1978; minimum daily, 205 microsiemens, April 16, 1979.
Water Temperature: (water years 1976 to current year): Maximum daily, 32.5° C, July 31, 1987; minimum daily, 0.0° C on many days during winter period.

### WATER-QUALITY DATA, WATER YEAR OCTOBER 1992 TO SEPTEMBER 1993

| DATE | TIME | DISCHARGE, INST. CUBIC FEET PER SECOND (00061) | SPECIFIC CONDUCT-ANCE (US/CM) (00095) | PH WATER WHOLE FIELD (STAN-DARD UNITS) (00095) | TEMP-ERATURE WATER (DEG C) (00010) | TURBID-ITY (NTU) (00076) | OXYGEN, DISSOLVED (MG/L) (00300) | OXYGEN, DISSOLVED (PERCENT SATURATION) (00301) | HARDNESS TOTAL (MG/L AS CACO3) (00900) | ALKALINITY WAT DIS TOT IT FILED MG/L AS CACO3 (39086) |
|---|---|---|---|---|---|---|---|---|---|---|
| NOV 24 | 1100 | 276000 | 266 | 8.1 | 8.0 | 320 | 9.3 | 77 | 110 | 96 |
| JAN 09 | 1145 | 145000 | 346 | 7.6 | 3.0 | 170 | 12.4 | 90 | 120 | 99 |
| MAY 20 | 0930 | 203000 | 434 | 7.6 | 16.5 | 190 | 7.4 | 75 | 180 | 143 |
| JUL 24 | 1245 | 321000 | 331 | 7.9 | 26.5 | 120 | 5.0 | 61 | 150 | 116 |
| AUG 06 | 1303 | 419000 | 382 | 6.9 | 24.5 | 140 | -- | -- | 150 | 112 |
| SEP 18 | 0900 | 202000 | 407 | 7.5 | 19.5 | -- | 8.8 | 94 | -- | -- |

## 05587455 MISSISSIPPI RIVER BELOW GRAFTON, IL
(National stream-quality accounting network station)

## WATER-QUALITY RECORDS

PERIOD OF RECORD.—March 1989 to current year.

PERIOD OF DAILY RECORD.—
Suspended Sediment Concentrations: October 1989 to current year.

EXTREMES FOR PERIOD OF DAILY RECORD.—
Suspended Sediment Concentrations: Maximum Daily, 1910 mg/L, May 23, 1990; minimum daily, 1 mg/L, Sept. 10, 1991.
Suspended Sediment Loads: Maximum daily, 1090000 tons, May 23, 1990; minimum daily, 186 tons, Sept. 10, 1991.

## WATER-QUALITY DATA, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

| DATE | TIME | DISCHARGE, INST. CUBIC FEET PER SECOND (00061) | SPECIFIC CONDUCT-ANCE (US/CM) (00095) | PH WATER WHOLE FIELD (STAN-DARD UNITS) (00095) | TEMP-ERATURE WATER (DEG C) (00010) | TURBID-ITY (NTU) (00076) | OXYGEN, DISSOLVED (MG/L) (00300) | OXYGEN, DISSOLVED (PERCENT SATURATION) (00301) | HARDNESS TOTAL (MG/L AS CACO3) (00900) | ALKALINITY WAT DIS TOT IT FILED MG/L AS CACO3 (39086) |
|---|---|---|---|---|---|---|---|---|---|---|
| NOV 26 | 1100 | 152000 | 467 | 7.7 | 4.0 | 94 | 11.2 | 93 | 200 | 152 |
| JAN 22 | 1330 | 75800 | 529 | 8.0 | 8.0 | 9.0 | 13.7 | 95 | 260 | 194 |
| MAR 24 | 1030 | 224000 | 463 | 7.9 | 7.9 | 47 | 13.4 | 103 | 220 | 165 |
| MAY 20 | 1100 | 97900 | 459 | 8.5 | 8.5 | 15 | 8.2 | 91 | 220 | 159 |
| JUL 14 | 1200 | 95800 | 422 | 7.2 | 7.2 | 44 | 6.2 | 74 | 190 | 142 |
| Sep 09 | 1130 | 62900 | 490 | 7.7 | 24.5 | 17 | 10.4 | 123 | 220 | 179 |

## 05587455 MISSISSIPPI RIVER BELOW GRAFTON, IL
(National stream-quality accounting network station)

## WATER-QUALITY RECORDS

PERIOD OF RECORD.—March 1989 to current year.

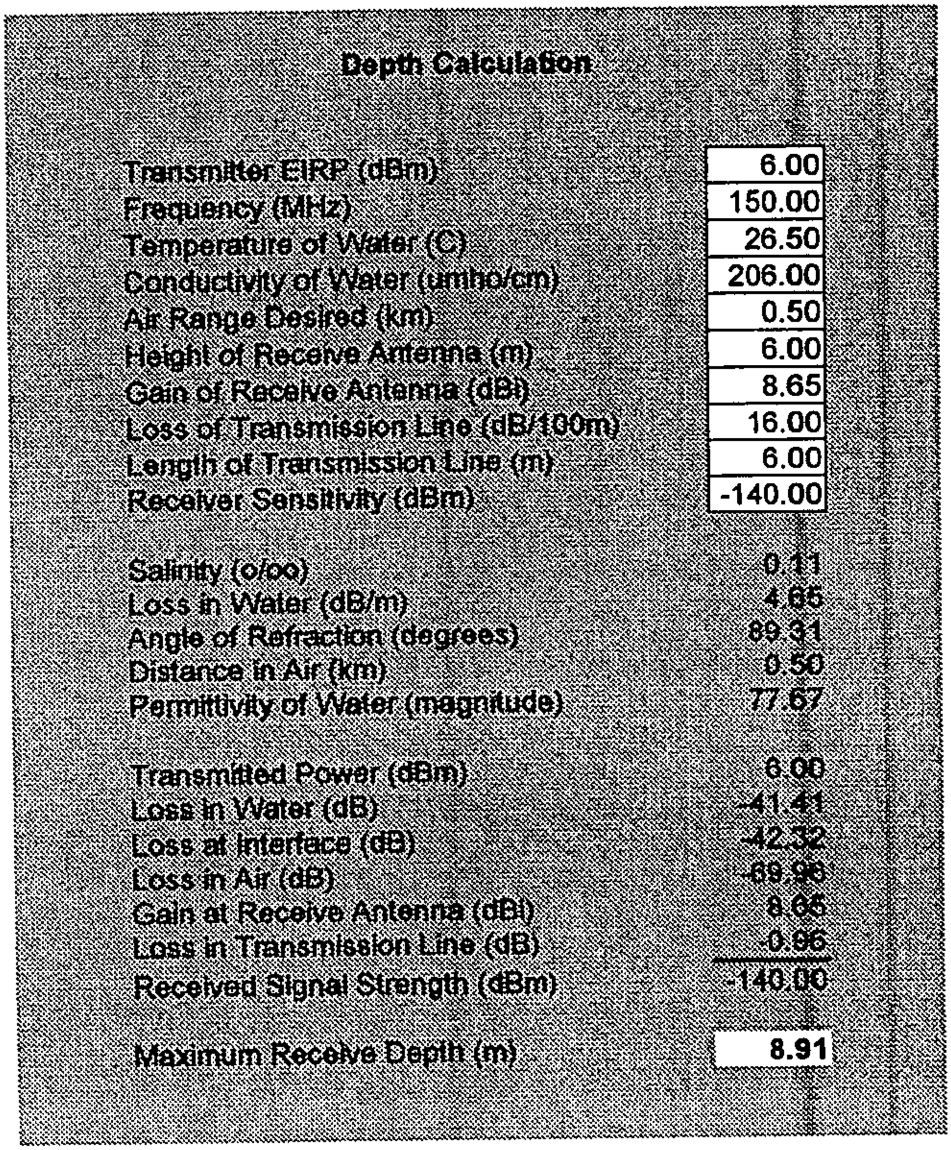
PERIOD OF DAILY RECORD.—
Suspended Sediment Concentrations: October 1989 to current year.

EXTREMES FOR PERIOD OF DAILY RECORD.—
Suspended Sediment Concentrations: Maximum Daily, 1910 mg/L, May 23, 1990; minimum daily, 1 mg/L, Sept. 10, 1991.
Suspended Sediment Loads: Maximum daily, 1090000 tons, May 23, 1990; minimum daily, 186 tons, Sept. 10, 1991.

## WATER-QUALITY DATA, WATER YEAR OCTOBER 1992 TO SEPTEMBER 1993

| DATE | TIME | DISCHARGE, INST. CUBIC FEET PER SECOND (00061) | SPECIFIC CONDUCT-ANCE (US/CM) (00095) | PH WATER WHOLE FIELD (STAN-DARD UNITS) (00095) | TEMP-ERATURE WATER (DEG C) (00010) | TURBID-ITY (NTU) (00076) | OXYGEN, DISSOLVED (MG/L) (00300) | OXYGEN, DISSOLVED (PERCENT SATURATION) (00301) | HARDNESS TOTAL (MG/L AS CACO3) (00900) |
|---|---|---|---|---|---|---|---|---|---|
| NOV 10 | 1015 | 120000 | 394 | 8.0 | 6.5 | 44 | 10.8 | 86 | 220 |
| DEC 18 | 1100 | 211000 | 440 | 7.9 | 2.0 | 110 | 12.5 | 88 | 200 |
| JAN 28 | 1030 | 157000 | 518 | 8.0 | 0.5 | 32 | 13.0 | 89 | 230 |
| FEB 19 | 1030 | 87000 | 602 | 8.0 | 0.5 | -- | 12.8 | 87 | -- |
| MAR 16 | 0930 | 209000 | 433 | 7.7 | 2.0 | 49 | 12.4 | 88 | 180 |
| APR 06 | 1130 | 273000 | 325 | 7.5 | 8.0 | 63 | -- | -- | 170 |
| May 13 | 1000 | 364000 | 387 | 7.9 | 18.0 | 22 | 11.6 | 120 | 210 |
| Jun 02 | 1100 | 217000 | 489 | 7.8 | 18.5 | 43 | 7.8 | 82 | 250 |
| Jul | | | | | | | | | |
| 15 | 1500 | 429000 | 375 | 7.5 | 24.0 | 50 | 6.2 | 72 | 170 |
| 17 | 1200 | 491000 | 394 | 7.6 | 24.0 | 33 | 5.8 | 67 | 180 |
| AUG 11 | 1300 | 405000 | 470 | 7.9 | 24.5 | 14 | 5.1 | 60 | 220 |
| SEP 01 | 1200 | 303000 | 474 | 7.8 | 26.5 | 26 | 6.6 | 82 | 210 |

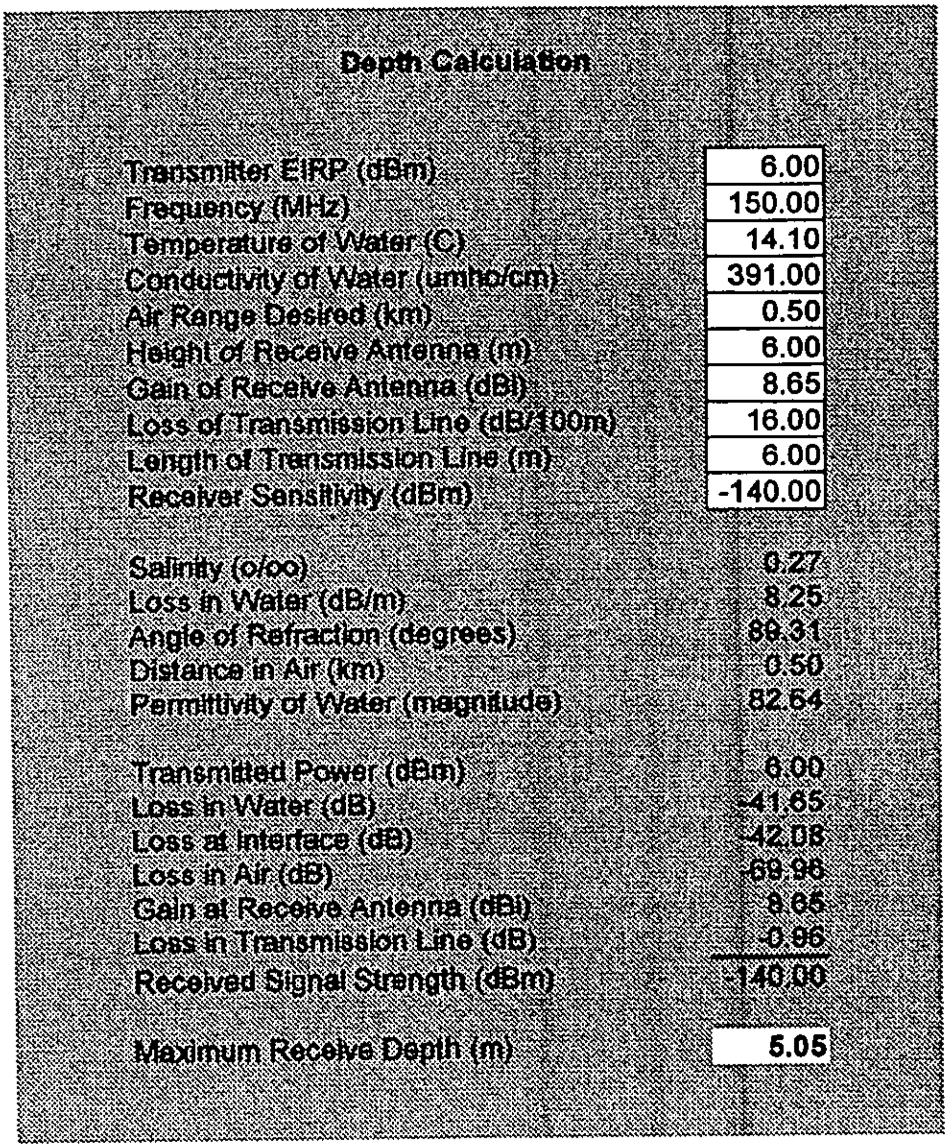
## D. RF MODEL WORKSHEETS

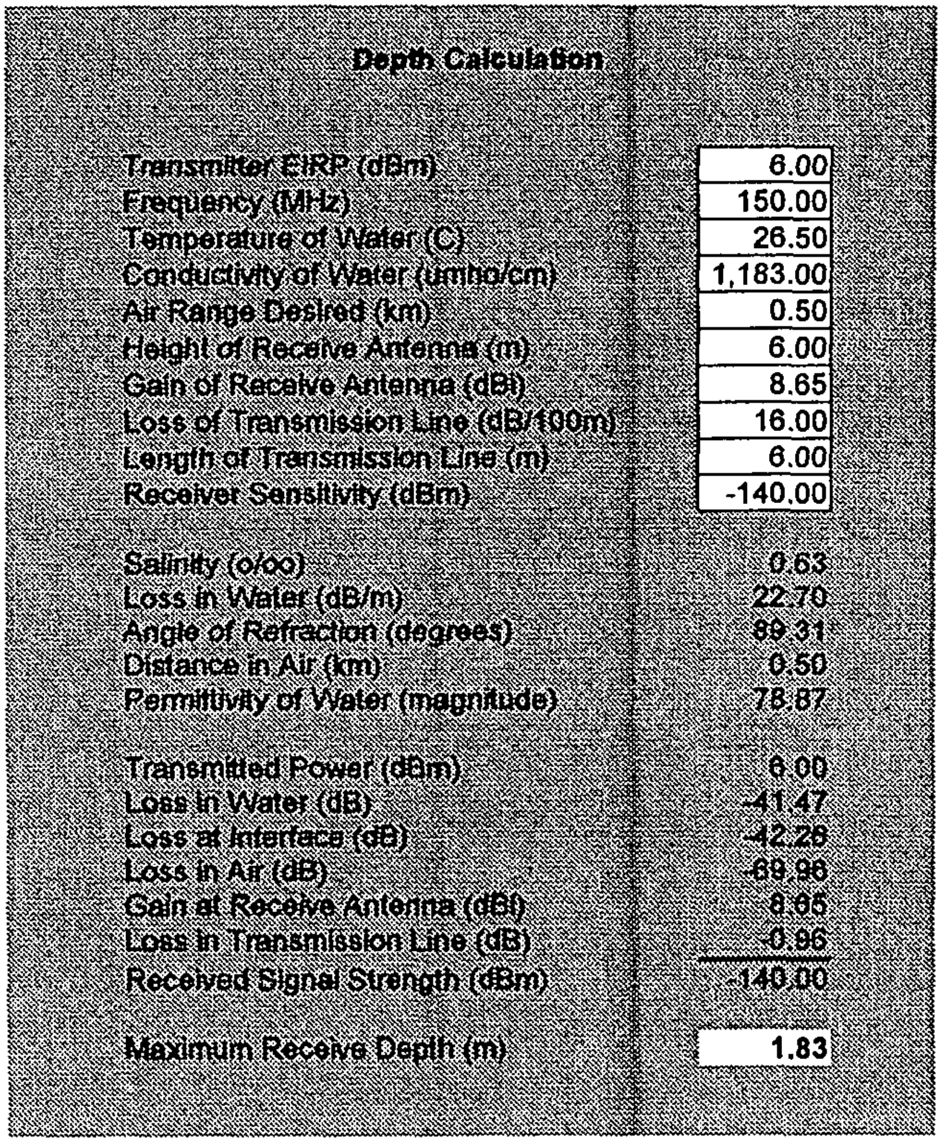


**Depth Calculation**

| | |
|---|---|
| Transmitter EIRP (dBm) | 6.00 |
| Frequency (MHz) | 150.00 |
| Temperature of Water (C) | 26.50 |
| Conductivity of Water (umho/cm) | 206.00 |
| Air Range Desired (km) | 0.50 |
| Height of Receive Antenna (m) | 6.00 |
| Gain of Receive Antenna (dBi) | 8.65 |
| Loss of Transmission Line (dB/100m) | 16.00 |
| Length of Transmission Line (m) | 6.00 |
| Receiver Sensitivity (dBm) | -140.00 |
| | |
| Salinity (o/oo) | 0.11 |
| Loss in Water (dB/m) | 4.65 |
| Angle of Refraction (degrees) | 89.31 |
| Distance in Air (km) | 0.50 |
| Permittivity of Water (magnitude) | 77.67 |
| | |
| Transmitted Power (dBm) | 6.00 |
| Loss in Water (dB) | -41.41 |
| Loss at Interface (dB) | -42.32 |
| Loss in Air (dB) | -69.96 |
| Gain at Receive Antenna (dBi) | 8.65 |
| Loss in Transmission Line (dB) | -0.96 |
| Received Signal Strength (dBm) | -140.00 |
| | |
| Maximum Receive Depth (m) | **8.91** |

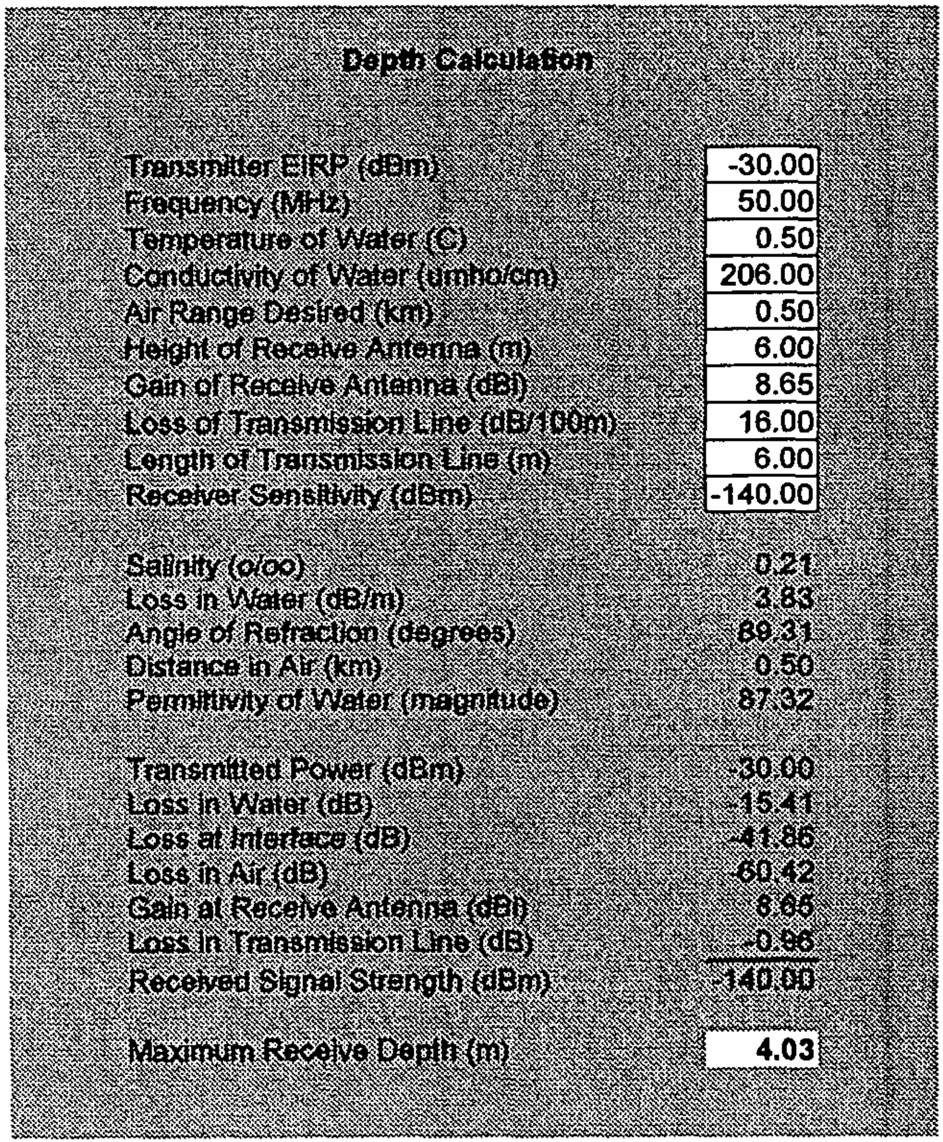
Table 31: Best Case 150 MHz RF





| Depth Calculation | |
|---|---|
| Transmitter EIRP (dBm) | 6.00 |
| Frequency (MHz) | 150.00 |
| Temperature of Water (C) | 26.50 |
| Conductivity of Water (umho/cm) | 1,183.00 |
| Air Range Desired (km) | 0.50 |
| Height of Receive Antenna (m) | 6.00 |
| Gain of Receive Antenna (dBi) | 8.65 |
| Loss of Transmission Line (dB/100m) | 16.00 |
| Length of Transmission Line (m) | 6.00 |
| Receiver Sensitivity (dBm) | -140.00 |
| | |
| Salinity (o/oo) | 0.63 |
| Loss in Water (dB/m) | 22.70 |
| Angle of Refraction (degrees) | 89.31 |
| Distance in Air (km) | 0.50 |
| Permittivity of Water (magnitude) | 78.87 |
| | |
| Transmitted Power (dBm) | 6.00 |
| Loss in Water (dB) | -41.47 |
| Loss at Interface (dB) | -42.28 |
| Loss in Air (dB) | -69.98 |
| Gain at Receive Antenna (dBi) | 8.65 |
| Loss in Transmission Line (dB) | -0.96 |
| Received Signal Strength (dBm) | -140.00 |
| | |
| **Maximum Receive Depth (m)** | **1.83** |

*Table 33: Worst Case 150 MHz RF*



**Depth Calculation**

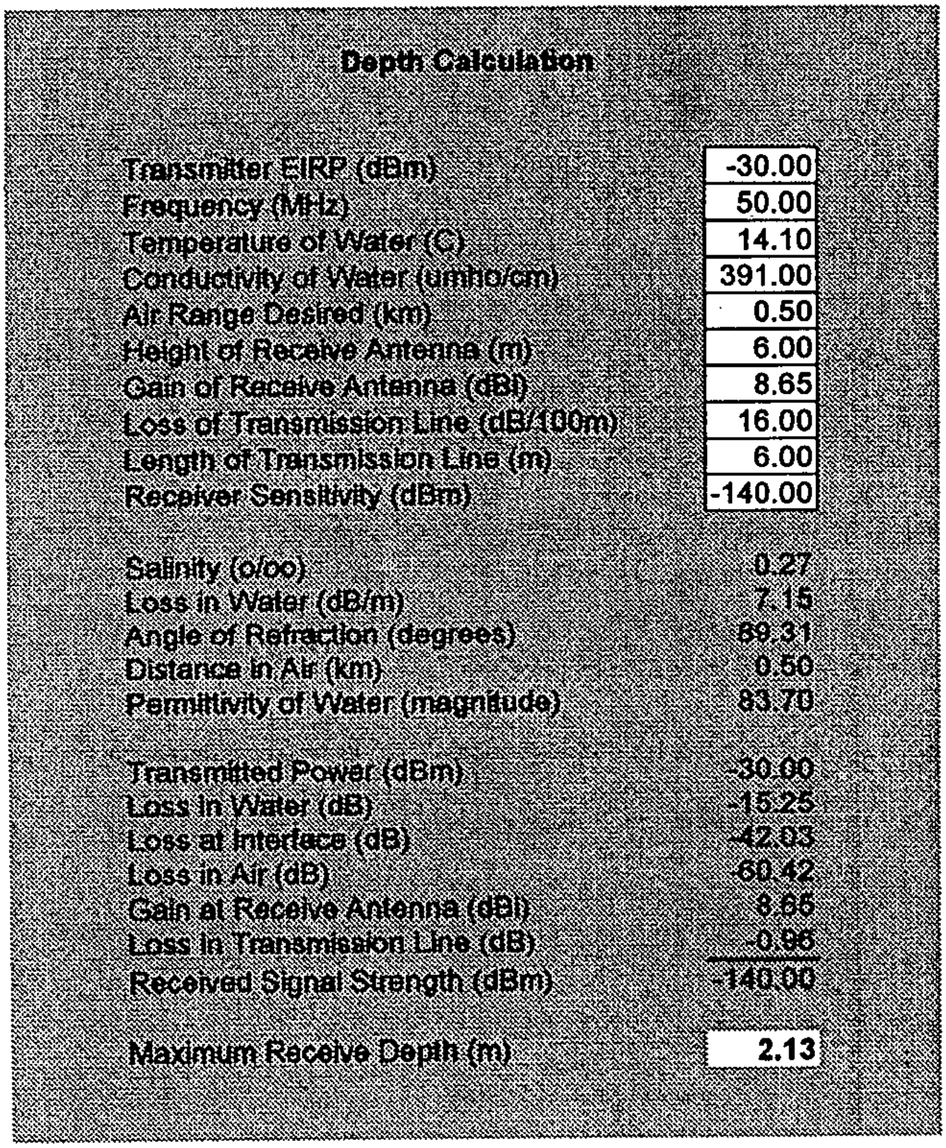
| | |
|---|---|
| Transmitter EIRP (dBm) | -30.00 |
| Frequency (MHz) | 50.00 |
| Temperature of Water (C) | 0.50 |
| Conductivity of Water (umho/cm) | 206.00 |
| Air Range Desired (km) | 0.50 |
| Height of Receive Antenna (m) | 6.00 |
| Gain of Receive Antenna (dBi) | 8.65 |
| Loss of Transmission Line (dB/100m) | 16.00 |
| Length of Transmission Line (m) | 6.00 |
| Receiver Sensitivity (dBm) | -140.00 |

| | |
|---|---|
| Salinity (o/oo) | 0.21 |
| Loss in Water (dB/m) | 3.83 |
| Angle of Refraction (degrees) | 89.31 |
| Distance in Air (km) | 0.50 |
| Permittivity of Water (magnitude) | 87.32 |

| | |
|---|---|
| Transmitted Power (dBm) | -30.00 |
| Loss in Water (dB) | -15.41 |
| Loss at Interface (dB) | -41.86 |
| Loss in Air (dB) | -60.42 |
| Gain at Receive Antenna (dBi) | 8.65 |
| Loss in Transmission Line (dB) | -0.96 |
| Received Signal Strength (dBm) | -140.00 |

| | |
|---|---|
| Maximum Receive Depth (m) | **4.03** |

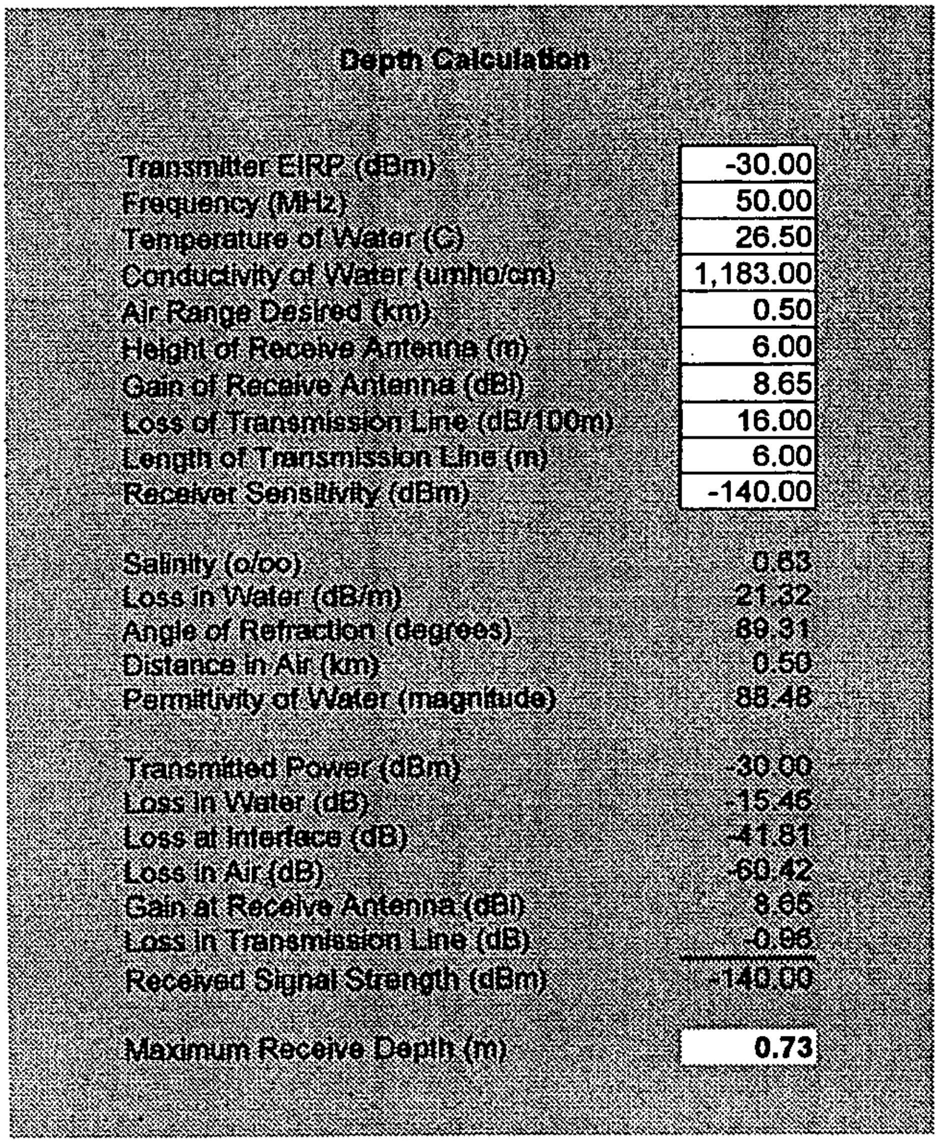
*Table 34: Best Case 50 MHz RF*



**Depth Calculation**

| | |
|---|---|
| Transmitter EIRP (dBm) | -30.00 |
| Frequency (MHz) | 50.00 |
| Temperature of Water (C) | 14.10 |
| Conductivity of Water (umho/cm) | 391.00 |
| Air Range Desired (km) | 0.50 |
| Height of Receive Antenna (m) | 6.00 |
| Gain of Receive Antenna (dBi) | 8.65 |
| Loss of Transmission Line (dB/100m) | 16.00 |
| Length of Transmission Line (m) | 6.00 |
| Receiver Sensitivity (dBm) | -140.00 |
| | |
| Salinity (o/oo) | 0.27 |
| Loss in Water (dB/m) | 7.15 |
| Angle of Refraction (degrees) | 89.31 |
| Distance in Air (km) | 0.50 |
| Permittivity of Water (magnitude) | 83.70 |
| | |
| Transmitted Power (dBm) | -30.00 |
| Loss in Water (dB) | -15.25 |
| Loss at Interface (dB) | -42.03 |
| Loss in Air (dB) | -60.42 |
| Gain at Receive Antenna (dBi) | 8.65 |
| Loss in Transmission Line (dB) | -0.96 |
| Received Signal Strength (dBm) | -140.00 |
| | |
| Maximum Receive Depth (m) | **2.13** |

*Table 35: Average Case 50 MHz RF*

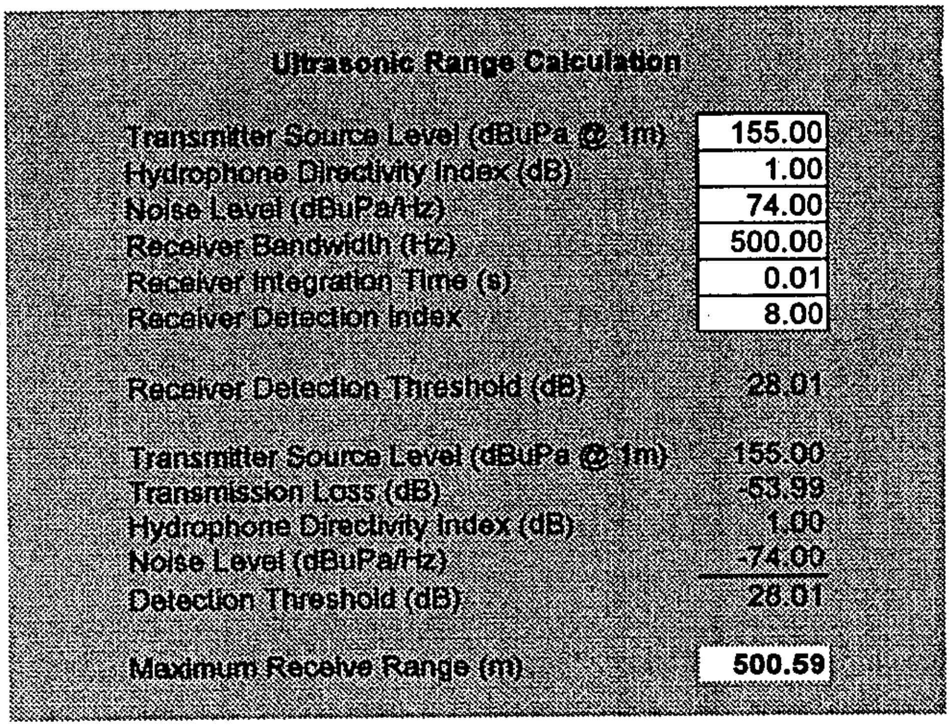


**Depth Calculation**

| | |
|---|---|
| Transmitter EIRP (dBm) | -30.00 |
| Frequency (MHz) | 50.00 |
| Temperature of Water (C) | 26.50 |
| Conductivity of Water (umho/cm) | 1,183.00 |
| Air Range Desired (km) | 0.50 |
| Height of Receive Antenna (m) | 6.00 |
| Gain of Receive Antenna (dBi) | 8.65 |
| Loss of Transmission Line (dB/100m) | 16.00 |
| Length of Transmission Line (m) | 6.00 |
| Receiver Sensitivity (dBm) | -140.00 |
| | |
| Salinity (o/oo) | 0.63 |
| Loss in Water (dB/m) | 21.32 |
| Angle of Refraction (degrees) | 89.31 |
| Distance in Air (km) | 0.50 |
| Permittivity of Water (magnitude) | 88.48 |
| | |
| Transmitted Power (dBm) | -30.00 |
| Loss in Water (dB) | -15.46 |
| Loss at Interface (dB) | -41.81 |
| Loss in Air (dB) | -60.42 |
| Gain at Receive Antenna (dBi) | 8.65 |
| Loss in Transmission Line (dB) | -0.96 |
| Received Signal Strength (dBm) | -140.00 |
| | |
| Maximum Receive Depth (m) | **0.73** |

*Table 36: Worst Case 50 MHz RF*

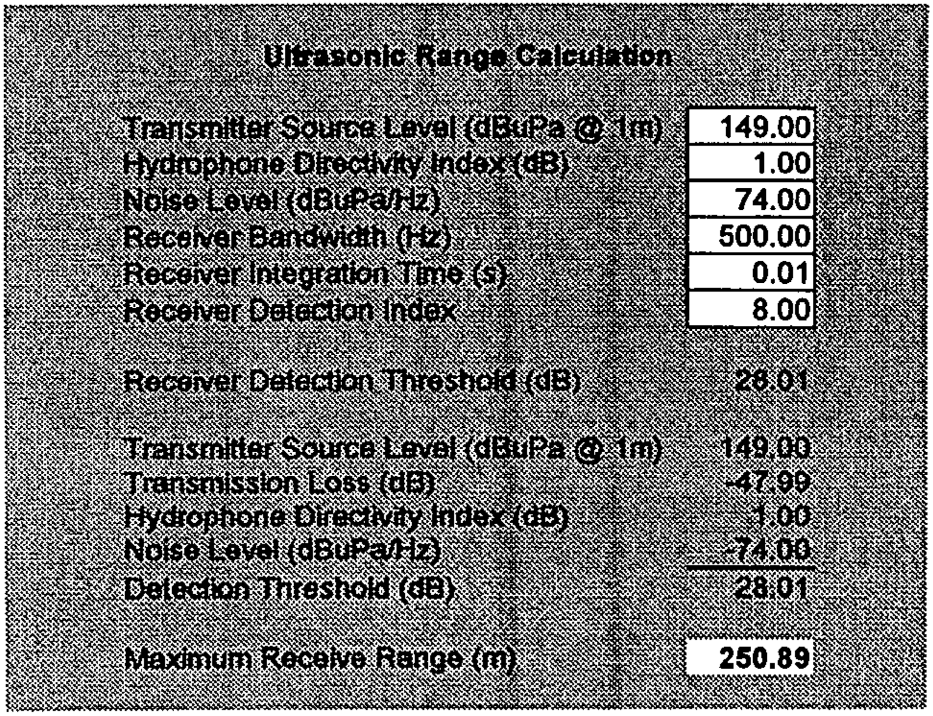
## E. ULTRASONIC MODEL WORKSHEETS



**Ultrasonic Range Calculation**

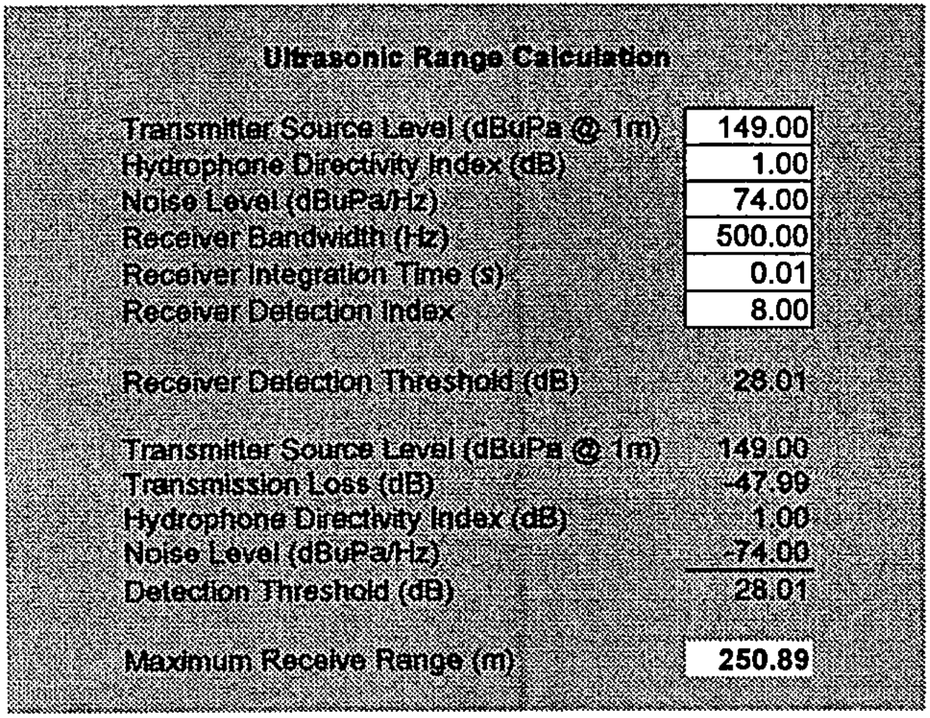
| | |
|---|---|
| Transmitter Source Level (dBuPa @ 1m) | 155.00 |
| Hydrophone Directivity Index (dB) | 1.00 |
| Noise Level (dBuPa/Hz) | 74.00 |
| Receiver Bandwidth (Hz) | 500.00 |
| Receiver Integration Time (s) | 0.01 |
| Receiver Detection Index | 8.00 |
| Receiver Detection Threshold (dB) | 28.01 |
| Transmitter Source Level (dBuPa @ 1m) | 155.00 |
| Transmission Loss (dB) | -53.99 |
| Hydrophone Directivity Index (dB) | 1.00 |
| Noise Level (dBuPa/Hz) | -74.00 |
| Detection Threshold (dB) | 28.01 |
| Maximum Receive Range (m) | 500.59 |

*Table 37: Ultrasonic Range Calculation Using Vemco Transmitter*



| Ultrasonic Range Calculation | |
|---|---|
| Transmitter Source Level (dBuPa @ 1m) | 149.00 |
| Hydrophone Directivity Index (dB) | 1.00 |
| Noise Level (dBuPa/Hz) | 74.00 |
| Receiver Bandwidth (Hz) | 500.00 |
| Receiver Integration Time (s) | 0.01 |
| Receiver Detection Index | 8.00 |
| | |
| Receiver Detection Threshold (dB) | 28.01 |
| | |
| Transmitter Source Level (dBuPa @ 1m) | 149.00 |
| Transmission Loss (dB) | -47.99 |
| Hydrophone Directivity Index (dB) | 1.00 |
| Noise Level (dBuPa/Hz) | -74.00 |
| Detection Threshold (dB) | 28.01 |
| | |
| Maximum Receive Range (m) | **250.89** |

*Table 38: Ultrasonic Range Calculation Using Sonotronics Transmitter*



| Ultrasonic Range Calculation | |
|---|---|
| Transmitter Source Level (dBuPa @ 1m) | 149.00 |
| Hydrophone Directivity Index (dB) | 1.00 |
| Noise Level (dBuPa/Hz) | 74.00 |
| Receiver Bandwidth (Hz) | 500.00 |
| Receiver Integration Time (s) | 0.01 |
| Receiver Detection Index | 8.00 |
| Receiver Detection Threshold (dB) | 28.01 |
| Transmitter Source Level (dBuPa @ 1m) | 149.00 |
| Transmission Loss (dB) | -47.99 |
| Hydrophone Directivity Index (dB) | 1.00 |
| Noise Level (dBuPa/Hz) | -74.00 |
| Detection Threshold (dB) | 28.01 |
| Maximum Receive Range (m) | **250.89** |

*Table 38: Ultrasonic Range Calculation Using Sonotronics Transmitter*

## APPENDIX B

**Pallid sturgeon relocations between Missouri River miles 98 and 250 from 1995 through1998.**

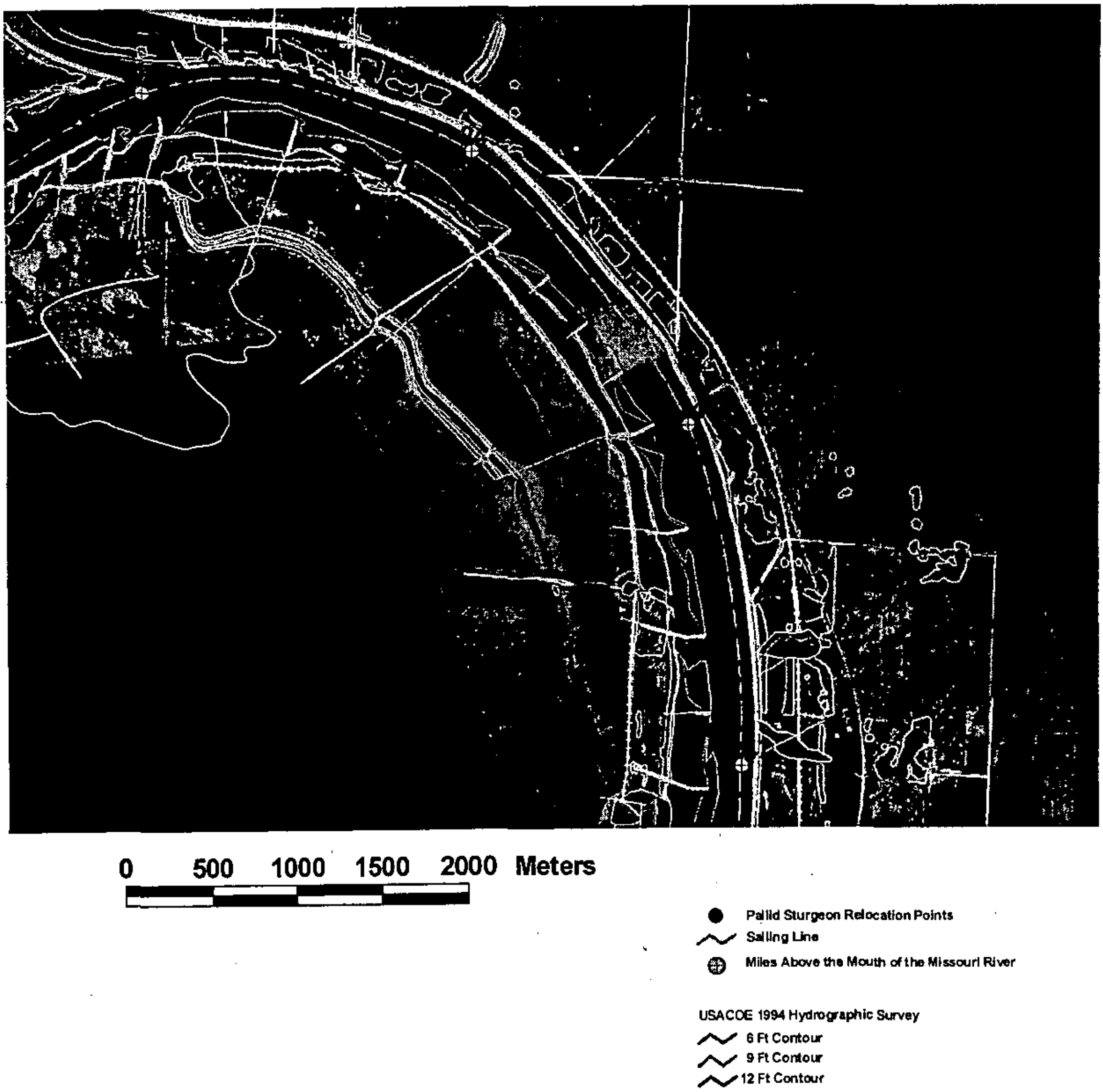


**Figure B1.** Pallid sturgeon relocations between Missouri River miles 247 and 250 from 1995 through1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

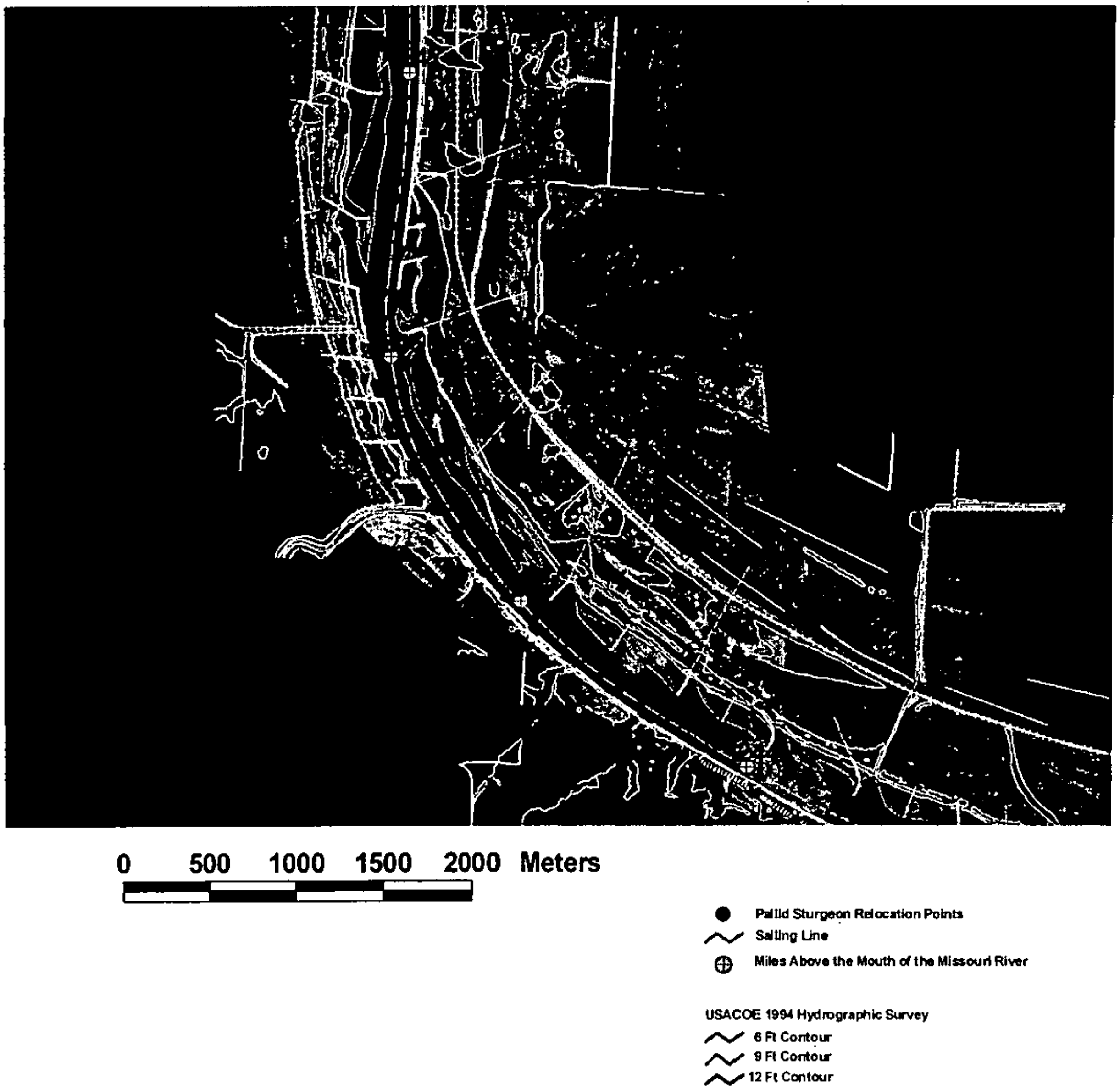


**Figure B2.** Pallid sturgeon relocations between Missouri River miles 244 and 247 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

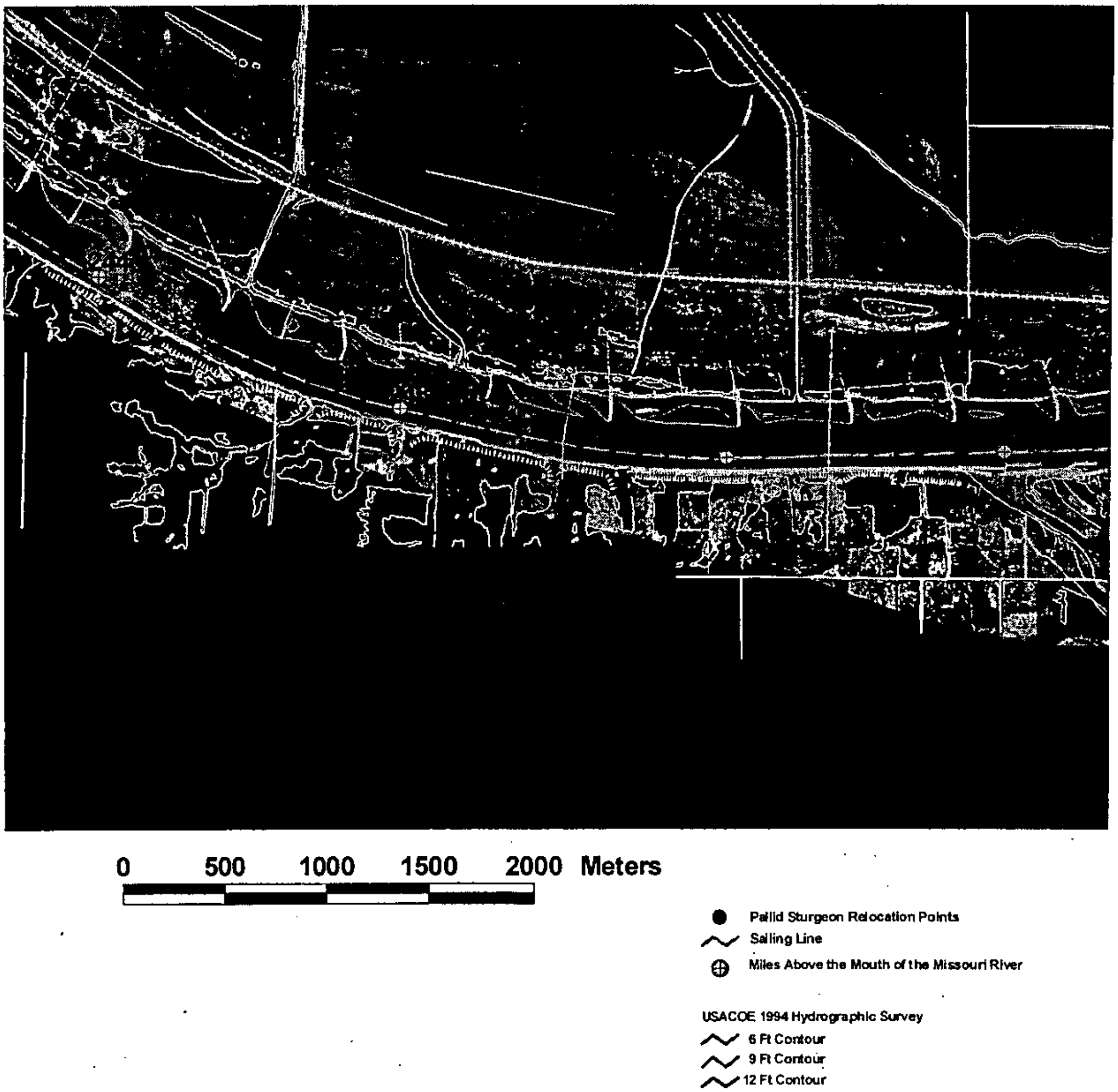


**Figure B3.** Pallid sturgeon relocations between Missouri River miles 241 and 244 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

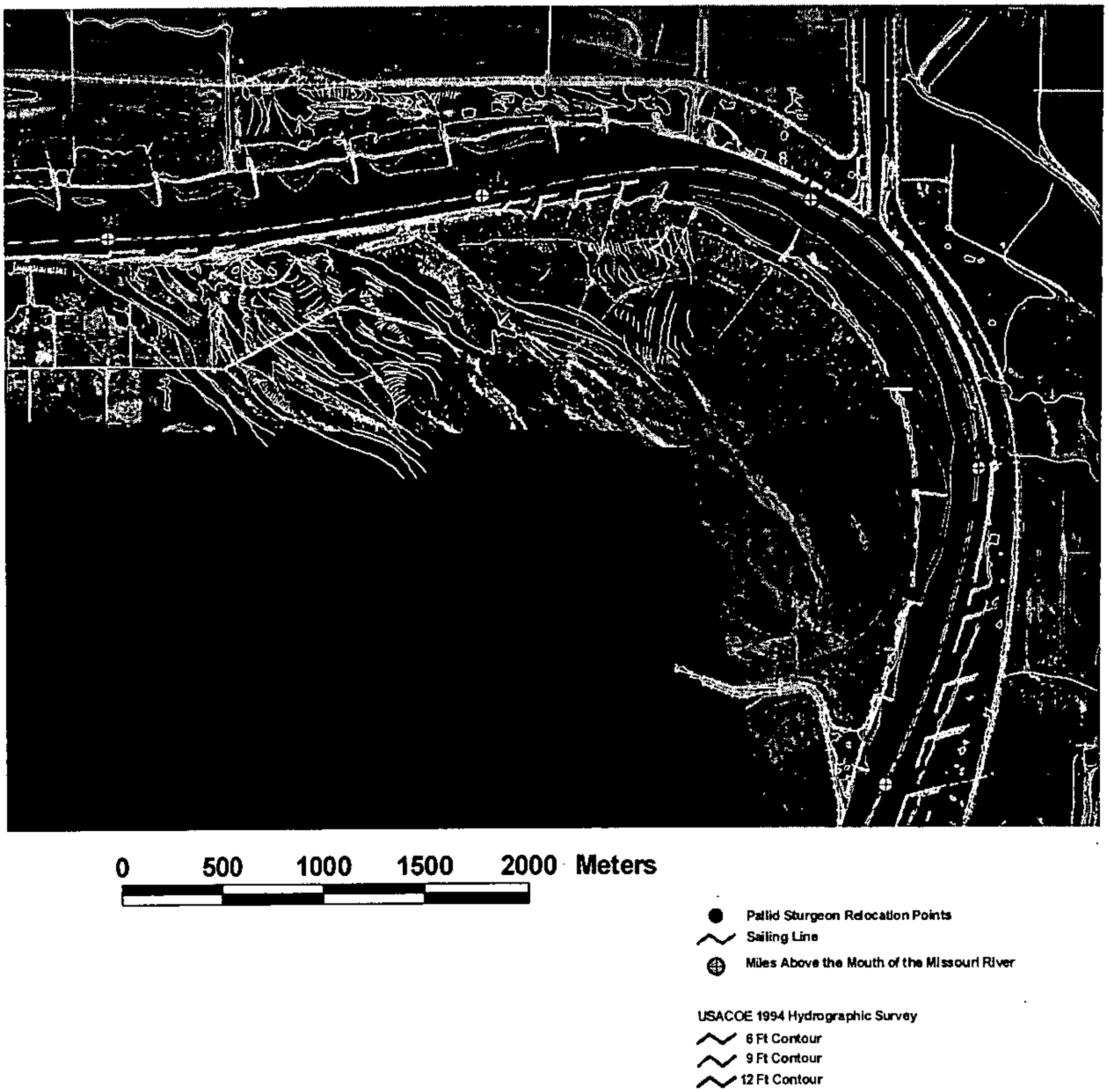


**Figure B4.** Pallid sturgeon relocations between Missouri River miles 237 and 241 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

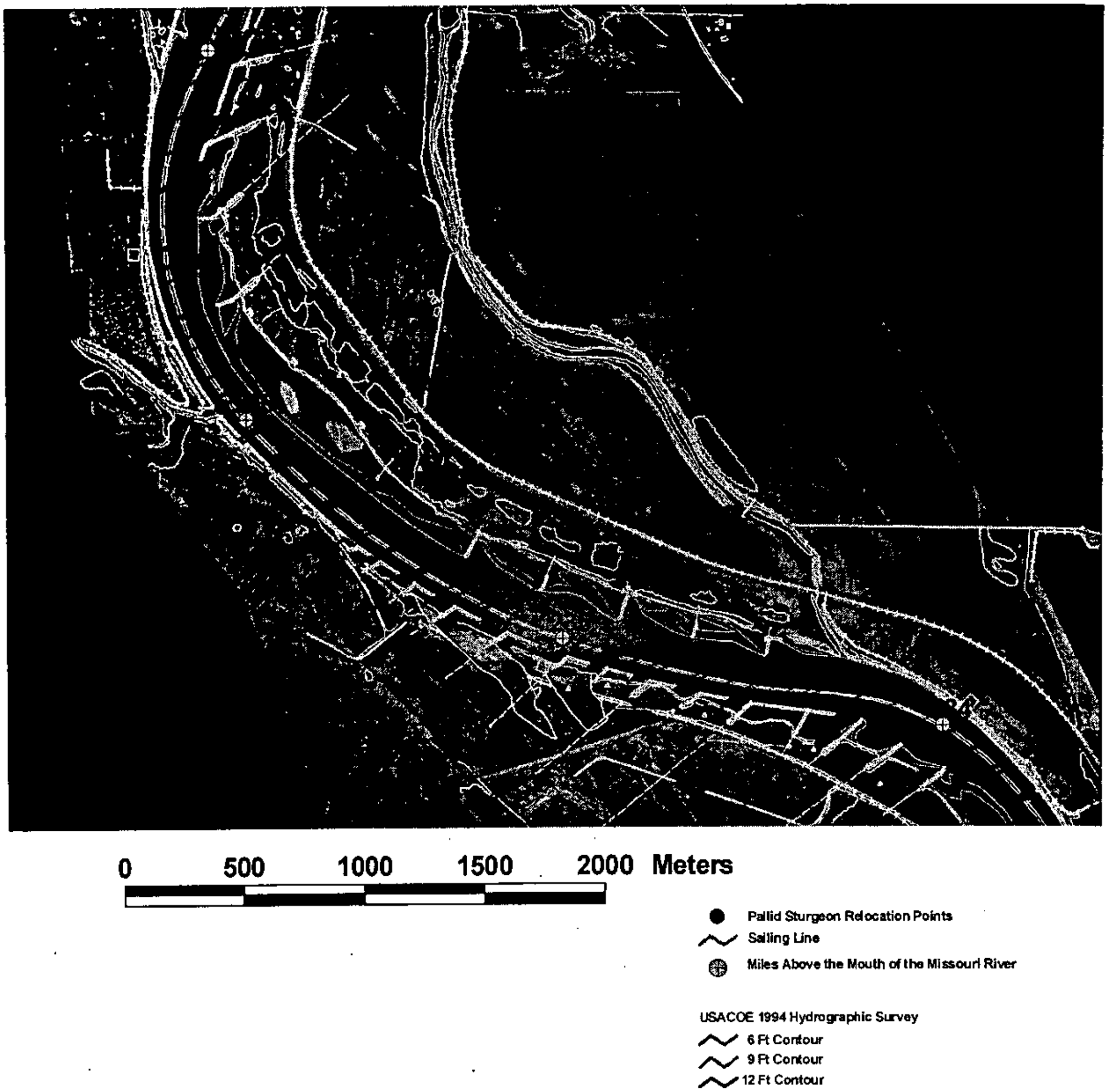


**Figure B5.** Pallid sturgeon relocations between Missouri River miles 234 and 237 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

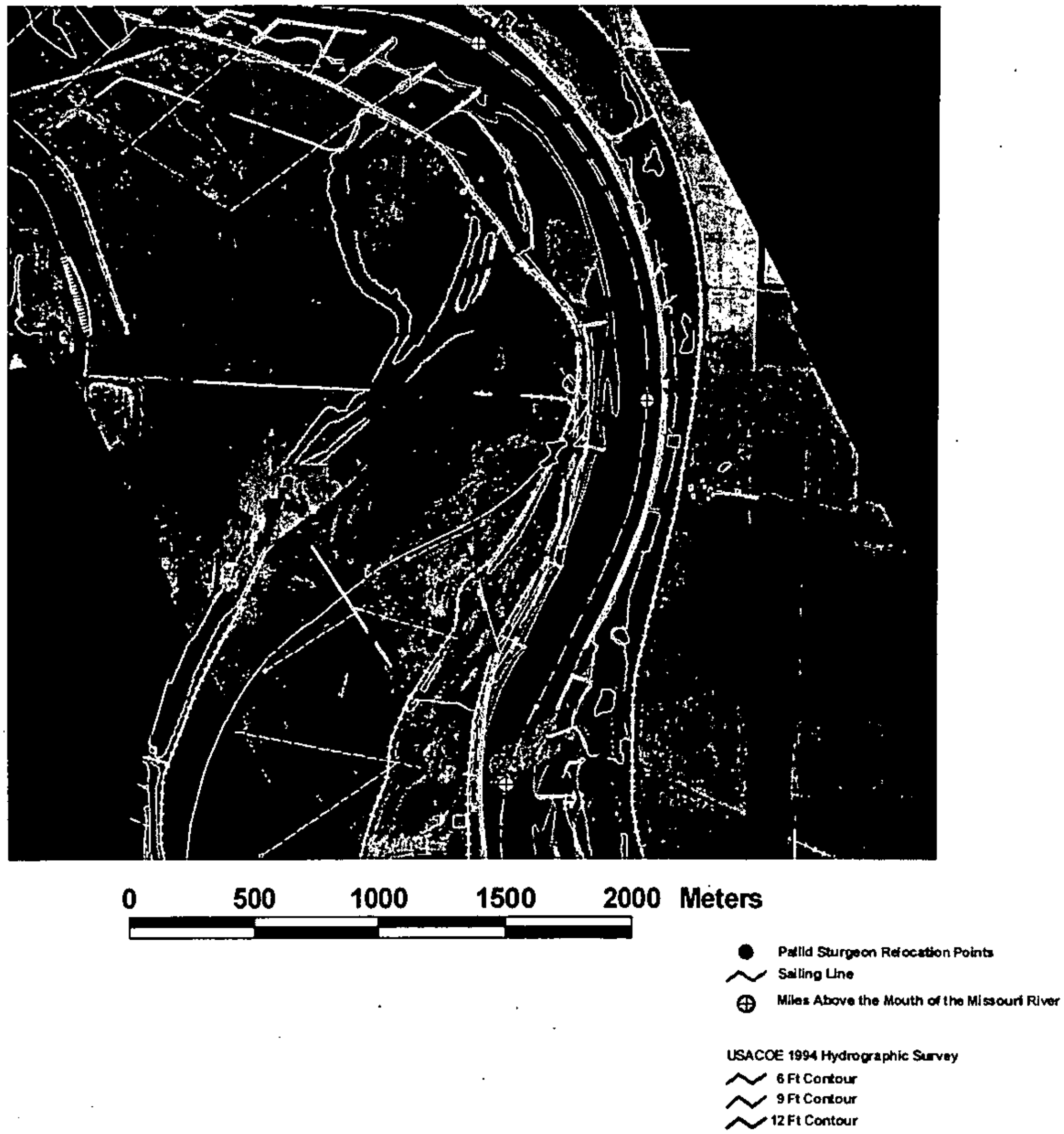


**Figure B6.** Pallid sturgeon relocations between Missouri River miles 232 and 234 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

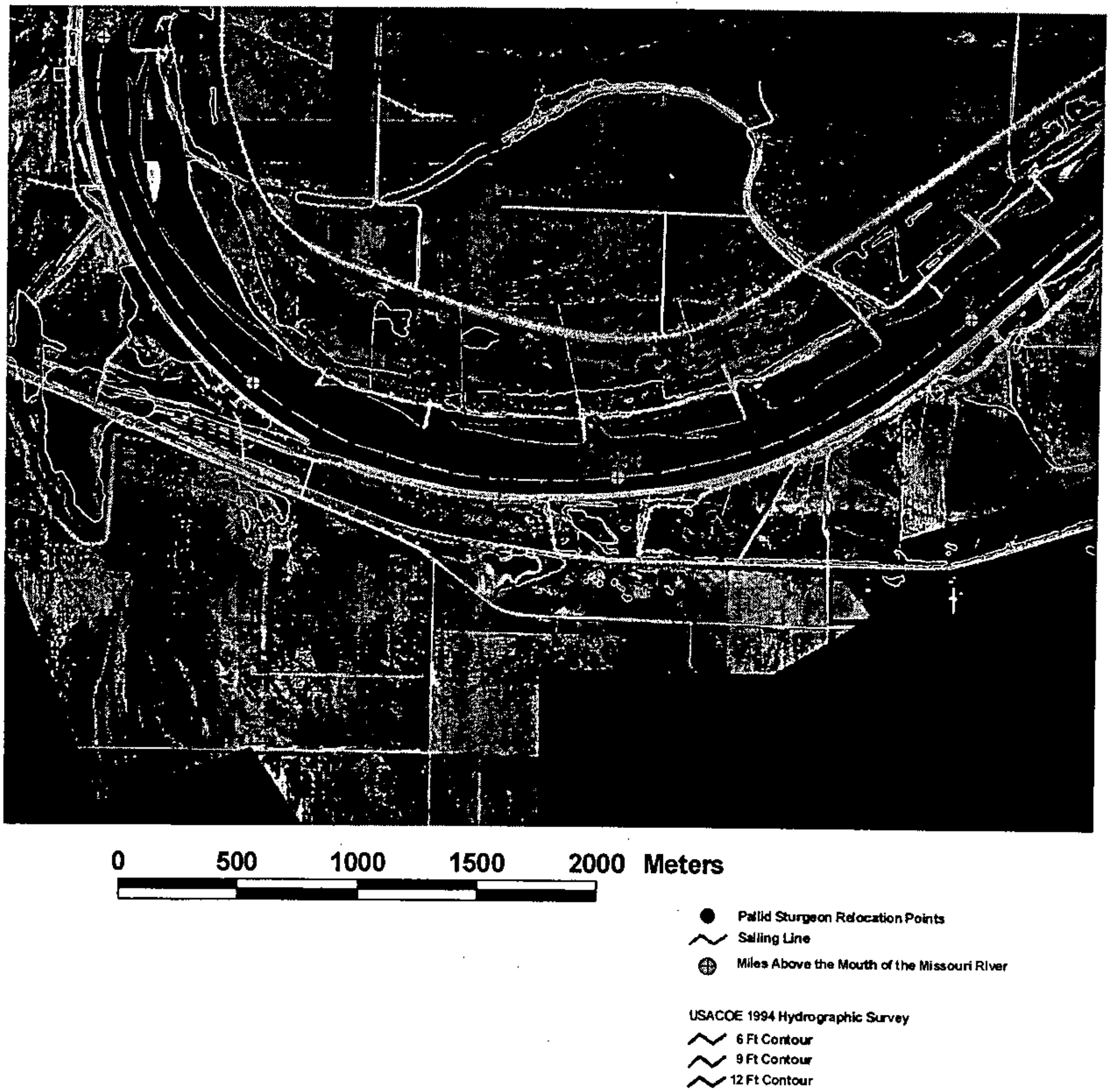


**Figure B7.** Pallid sturgeon relocations between Missouri River miles 229 and 232 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

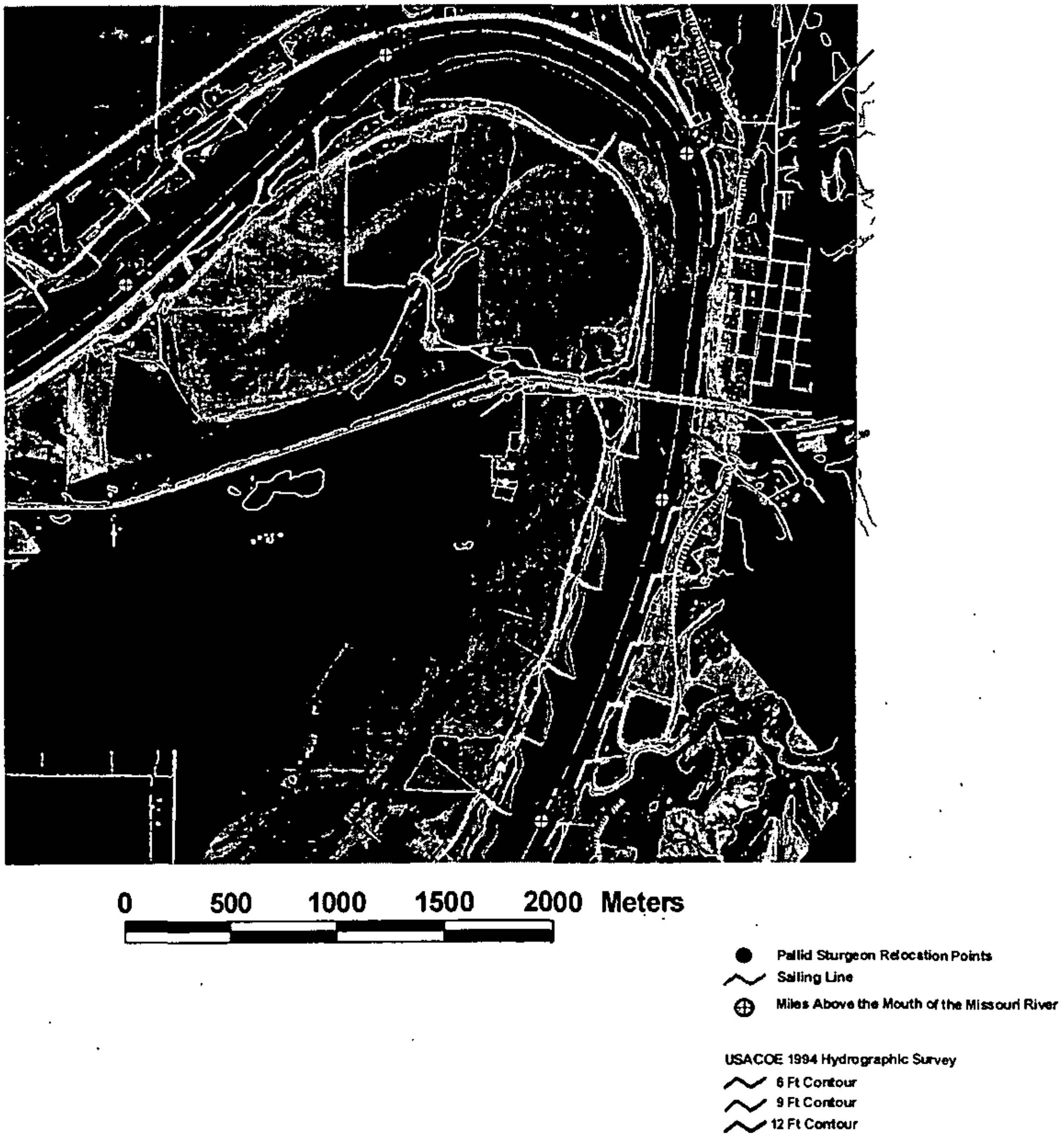


**Figure B8.** Pallid sturgeon relocations between Missouri River miles 225 and 229 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

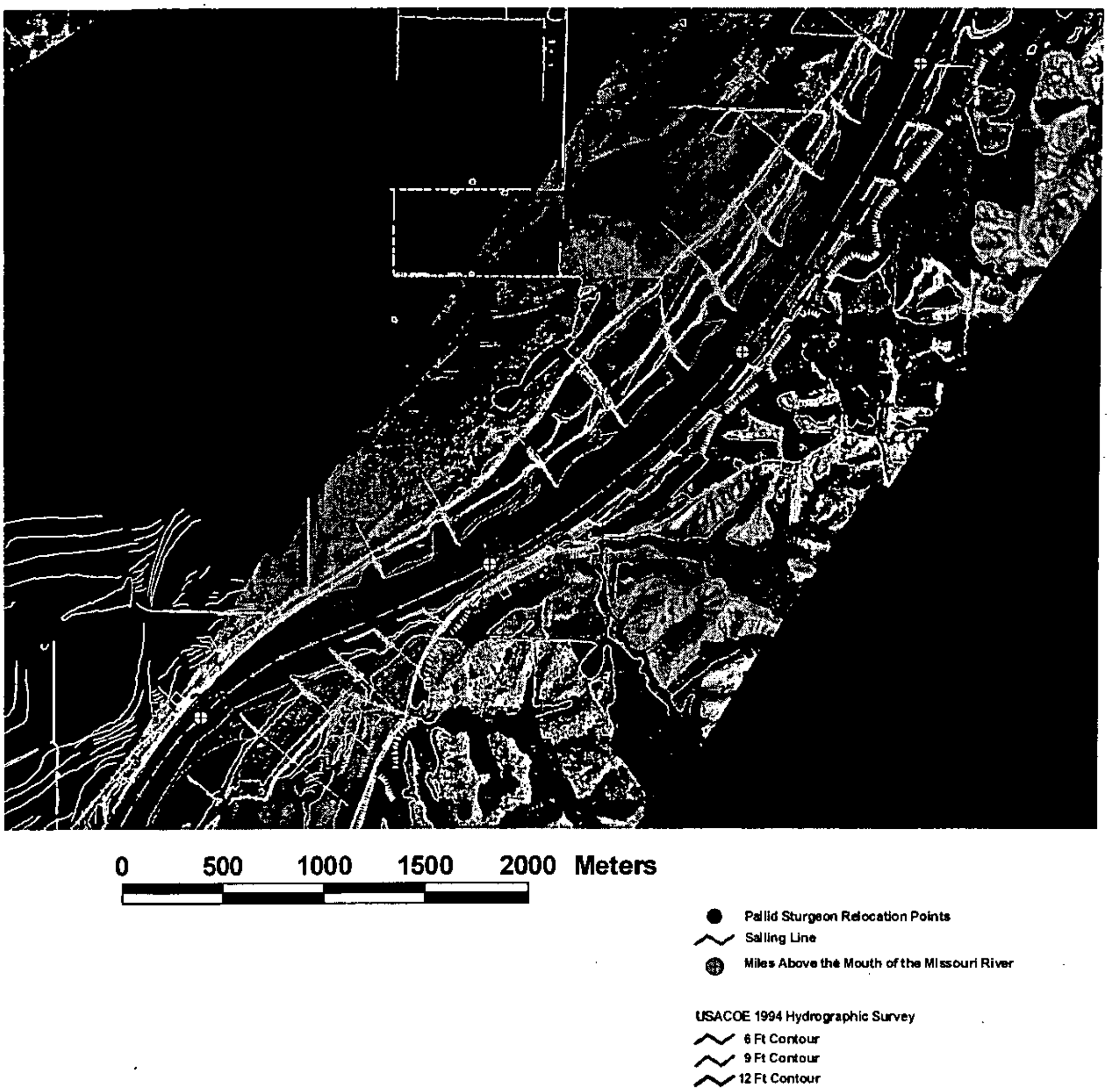


**Figure B9.** Pallid sturgeon relocations between Missouri River miles 222 and 225 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

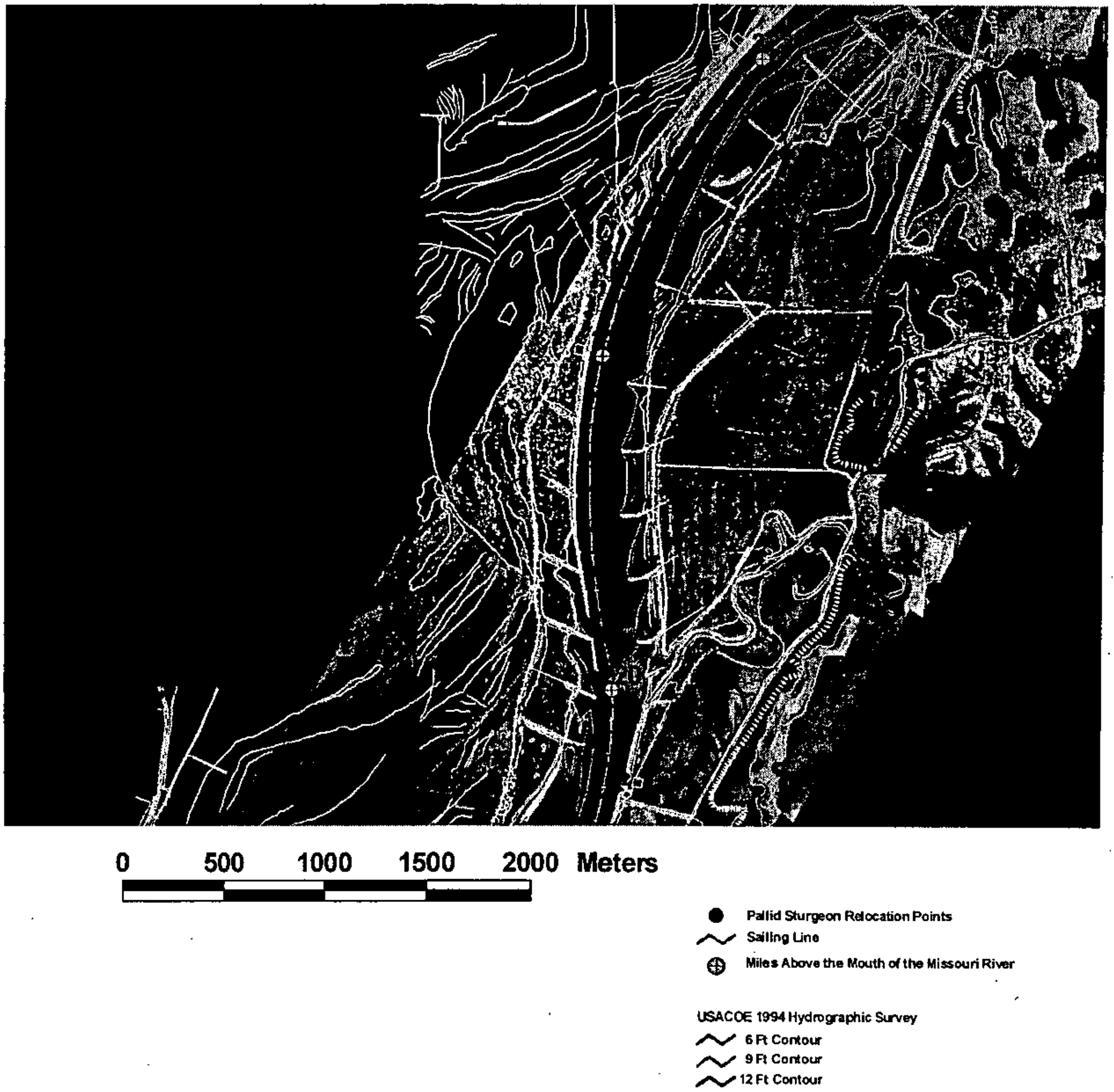


**Figure B10.** Pallid sturgeon relocations between Missouri River miles 220 and 222 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

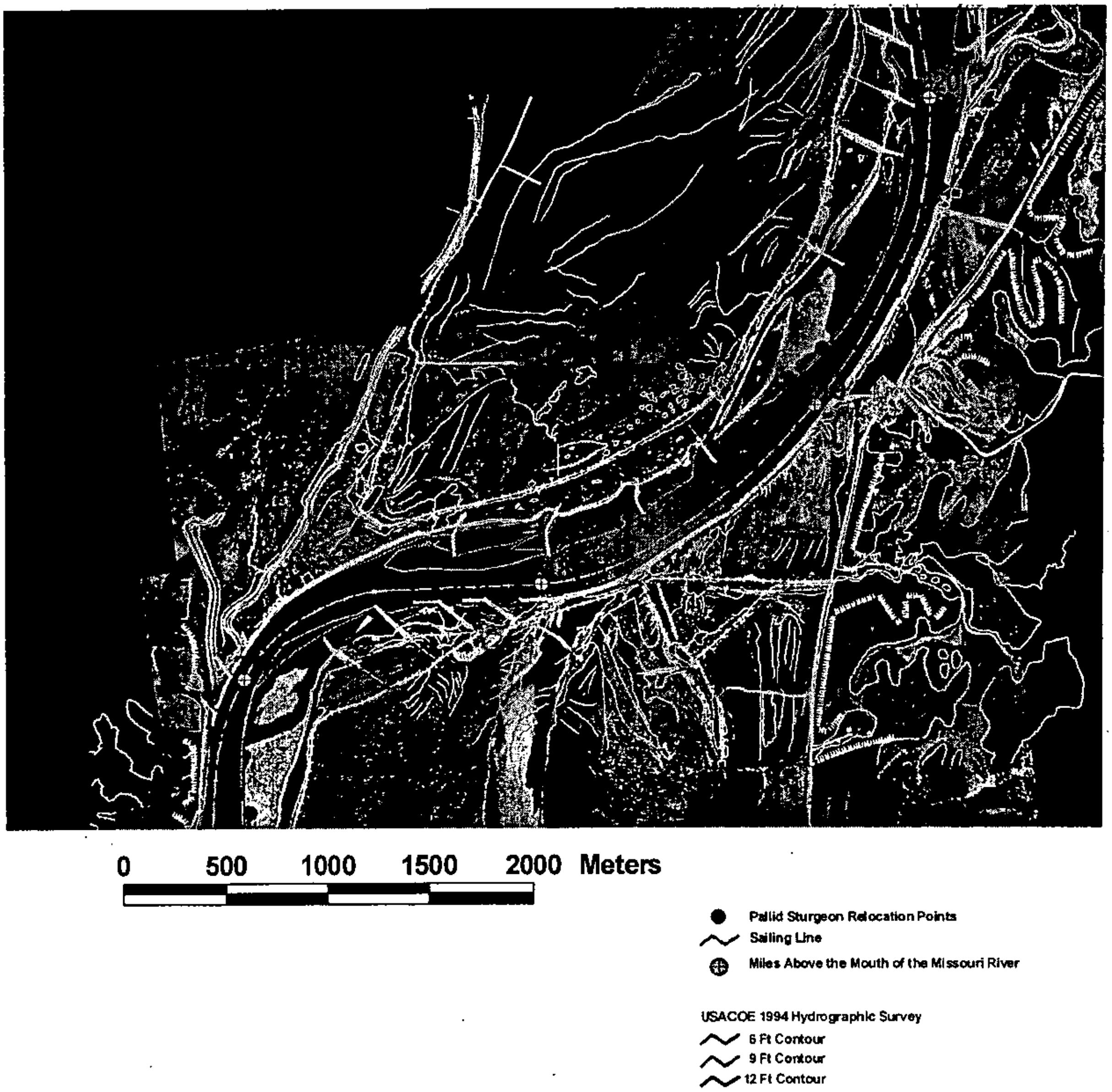


**Figure B11.** Pallid sturgeon relocations between Missouri River miles 217 and 220 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

**Figure B12.** Pallid sturgeon relocations between Missouri River miles 214 and 217 from 1995 through 1998. Point locations are plotted on 2000 DOQ photos collected during low flow. The U.S. Army Corps of Engineers 1994 Hydrographic Survey has been added to illustrate the generalized river morphology. Depth contours reference the construction plane elevation.

March 3, 1849

# United States Department of the Interior

U. S. GEOLOGICAL SURVEY

Columbia Environmental Research Center
4200 New Haven Road
Columbia, Missouri 65201

February 28, 2003

Peter Fasbender
U.S. Fish and Wildlife Service
Bisphop Henry Federal Building
One Federal Drive
Ft. Snelling, MN 55111-4056

Re: Project Completion Summary Report

Title: "Development of Methods to Monitor Pallid Sturgeon (*Scaphirhynchus albus*)
Movement and Habitat Use in the Lower Missouri River, "

Author(s): Aaron J. DeLonay and Edward E. Little

As per required ESA permit reporting requirements, please find enclosed a copy of the completed summary report documenting this Center's activities in developing methods to track and monitor the movement of pallid sturgeon in the Lower Missouri River from 1995 through 2000. The report analyzes the constraints that must be considered when selecting telemetry systems for monitoring riverine fishes in the severe conditions of the Lower Missouri River. The approach used in this study illustrates that telemetry is a viable tool for supplementing conventional fishery sampling techniques to determine the requirements of riverine species, including the endangered pallid sturgeon. Data included in this report is in preparation for submission to peer reviewed journals.

Copies of this report will be forwarded to USFWS field personnel and to members of the pallid sturgeon recovery team. Please contact the authors of the report or myself (Ph:573-876-1900; Fx:573-876-1855) with any questions or concerns, technical or otherwise.

Best regards,

Michael Mac

Dr. Michael J. Mac
Center Director

cc: Steve Krentz/Pallid Sturgeon Recovery Coordinator
Charlie Scott/Columbia ES
Jane Ledwin/Columbia ES
Jim Milligan/Columbia FRO
Joyce Collins/Marion-ES

Encl:

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